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On the Cover: Sugar cane breeding plots at Kailua, Oahu.

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THE 1957 SUGAR CANE EXPEDITION TO MELANESIA

JOHN N. WARNER AND CARL O. GRASSL *

INTRODUCTION

The Plant Introduction Branch of the United States Department of Agriculture, with the cooperation of the Hawaiian Sugar Planters' Association and the Queensland Bureau of Sugar Experiment Stations, sponsored an extensive expedition to collect new sugar cane breeding material in Melanesia during the early part of 1957. Melanesia, with major emphasis on unexplored areas in New Guinea, was selected because here is found an extensive flora of the genus *Saccharum*, which includes cultigens of *S. officinarum* L. and *S. edule* Hask., as well as vast areas of the wild sugar canes, *S. spontaneum* L. and *S. robustum* Brandes and Jeswiet ex Grassl.

Genes contained in the canes of collections held by cane breeders throughout the world are used as their building blocks in synthesizing new varieties. As genetic variability is the foundation of both hybridization and selection, sugar cane breeders are constantly on the alert for new breeding material which may offer the chance for continued progress. It was in the hope of augmenting the World Collection of Sugar Cane Germplasm that the 1957 expedition was organized and conducted.

Lending a measure of urgency to the need for collecting varieties of *S. officinarum* is the fact that, as civilization encroaches on the primitive societies of Melanesia, subsistence agriculture deteriorates. Varieties of *S. officinarum*, commonly known as "noble" canes, are found only as cultivated plants in native gardens where they are grown for chewing purposes (Figures 1 and 2). As the natives become more civilized, they tend to abandon traditional subsistence gardens in favor of more intensive farming of cash crops or of purchasing foodstuffs from merchants. Sugar cane is then grown only as a novelty instead of as a staple food and the number of varieties rapidly diminishes.

Sugar cane breeders everywhere are agreed that there is a great need to continue collecting the noble canes and preserving them in living herbaria so they may be available for eventual trial in their breeding programs. At present, the World Collections of Sugar Cane Germplasm are located at Canal Point, Florida, U.S.A. (maintained by the U.S. Department of Agriculture) and near Coimbatore, South India (maintained by the Sugarcane Breeding Institute of the Government of India). In addition, the USDA maintains a secondary collection at Salinas, California, U.S.A. Each sugar cane breeding station maintains partial collections of the original noble canes.

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Figure 1. A native subsistence garden near Wau. Chewing canes, tied to supporting poles, are interplanted with sweet potatoes.

Figure 2. Collection of noble canes from a garden at Kaisenik, near Wau.

Perhaps a less urgent, but nonetheless important, objective of the expedition was the collection of *S. robustum* and *S. spontaneum*, the truly wild members of the genus *Saccharum*. While these types survive in the wild, and thus will be available for many years to come, they are of interest to sugar cane breeders as sources of vigor, disease resistance, desirable habit for certain conditions, and other characters (Figure 3). Collection of various forms of *S. robustum*, the wild group most closely related to the noble canes, is likely to shed further light on the origin of *S. officinarum* and the taxonomic relationships between the species.

The New Crops Research Branch also charged the expedition with the collection of other members of the *Andropogoneae* and other plants of possible economic interest.

MATERIALS AND METHODS

In general, the plan of the expedition was to take advantage of available air services between localities (usually government stations) and then, with these stations as bases, to use such surface transport as might be available for collecting in the vicinity. While in the New Guinea area, 78 hops by airplane were made and several hundred miles were covered by jeep, work boat, canoe, on horseback and on foot.

Cuttings of the noble canes were obtained from the native gardens by barter, efforts being made to select healthy, pest-free material. Brief descriptions were made on the spot. Cuttings of representative clones of *S. edule* and *S. robustum* were also taken. Additional collections of *S. robustum* and collections of *S. spontaneum* were taken as mature seed.

Usually two cuttings, each with three or more nodes, were shipped to each of two quarantine stations by air freight. The cuttings were dusted with DDT, wrapped in polyethylene sheeting, and then rolled in corrugated paper. After bundling securely to prevent damage to the buds in transit, the roll of cuttings was wrapped in heavy paper. The packing materials were kindly furnished by the Queensland Bureau of Sugar Experiment Stations. The Bureau of Sugarcane Experiment Stations established quarantine facilities for cuttings at Magnetic Island, on the Great Barrier Reef near Townsville, Queensland, Australia. Duplicate sets of cuttings of most of the collections were shipped to Washington, D.C., for quarantine at Beltsville, Maryland. After quarantine the various canes will be placed in the World Collections and will be available to sugar cane breeders through normal procedures.

Seed collections were placed in kraft paper bags and dried before being shipped in plastic bags (with a desiccating agent) to Washington, D.C. There a portion of each lot was germinated in quarantine and the balance was made available to interested sugar cane breeders. Selected lots were germinated in the Molokai quarantine greenhouses of the HSPA. The USDA will place selected representative seedlings of each lot of *Saccharum* seedlings in the Canal Point collection.

HISTORY OF SUGAR CANE COLLECTIONS IN NEW GUINEA

The first recorded sugar cane collecting in New Guinea, as far we as know, was done about 1875 by O. C. Stone, a naturalist visiting the area near what is now Port Moresby (8). He shipped or carried to Brisbane eight varieties of native chewing canes.

Figure 3. The authors on a roadside near Port Moresby. Mr. Grassl is examining the flowers of **S. spontaneum**. (Photo by Dr. Dorothy Shaw, Dept. of Agric., Port Moresby)

Subsequent expeditions to Papua, and later to the Mandated or Trust Territory of New Guinea, have been described in detail by Buzacott and Hughes (2) and are summarized in Table 1.

ITINERARY OF 1957 EXPEDITION

The purpose of the expedition was to cover a large area, sampling as many and as widely separated areas as time would allow. With this in mind, an itinerary was evolved which took the writers by air to locations around which they collected for periods ranging from a part of a day to a week, before flying on to the next stop.

The first six weeks, beginning on March 15, were spent in Australian-administered New Guinea. The month of May was spent in Netherlands New Guinea, followed by another two-week period in Australian New Guinea. In mid-June, eight days were spent in the British Solomon Island Protectorate before returning to Australian New Guinea for another ten days. Most of the areas covered were at elevations of less than 1000 feet. The intermediate highlands area was sampled at Garaina (one day), Wantoat (one day), Menyamya-Bulolo-Wau (two days), and Lumi (two days). The highlands area was visited on three occasions, Telefomin (two days), Nondugl-Baiyer River-Tari (12 days) and the Wissel Lakes (two days). A map of New Guinea will be found in Appendix G.

DISTRIBUTION OF SACCHARUM sp. IN NEW GUINEA AND THE SOLOMON ISLANDS

The collections made are tabulated in the appendices. The clones of *S. officinarum*, *S. robustum* and *S. edule* are listed in Appendices A, B, and C, respectively. Lists of the seed of *S. robustum*, *S. spontaneum* and miscellaneous grasses related to *Saccharum*, are given in Appendices D, E and F, respectively.

TABLE 1—SUMMARY OF SUGAR CANE COLLECTING IN NEW GUINEA—1875-1951

Year	Sponsoring Organization	Personnel	Area Visited	Number Varieties Collected	Number Varieties Remaining in "World Collections"
1875	———	Stone	Port Moresby	8	None
1892	Q'Land. Dept. of Agric.	Cowley	Mabaduan Port Moresby Samarai	40 (*1*)	None
1893	Q'Land. Dept. of Agric.	Cowley	Yule Is.	11	None
1895–96	Q'Land. Dept. of Agric.	Tryon	Port Moresby Milne Bay Rigo	72	5
1908	C.S.R. Co. (*2*)	Dennis Blaxland	Milne Bay Louisade Archipelago Trobriand Is. D'Entrecasteaux Is. N. Coast N.G. to Buna	125	None
1912	BSES (*3*)	Wells	Sogeri Kokoda Rigo	119	None
1914	C.S.R. Co. (*2*)	Carne Baker	Buna Kokoda	106	3
1921	C.S.R. Co. (*2*)	Chinnery Joubert	Rigo Tabar Is. & New Ireland	40 18	24 12
1928	USDA	Brandes Jeswiet (*6*) Pemberton (*7*)	Fly R. Palmer R. Ok-Tedi R. Strickland R. Lake Murray Port Moresby Rigo Ambunti, Sepik R. Marienburg, Sepik R. Lae	292 (*4*)	126 (*5*)
1937	HSPA	Lennox Pemberton	New Hanover New Ireland N. New Britain Kainantu Wau-Bulolo Salamaua	6	1 plus seedlings see note (*8*)
1951	BSES	Buzacott Hughes Warner (*7*)	Port Moresby Lae-Markham R. Kainatutu-Aiyura Goroka Chimbu Mt. Hagen Mendi	165 (*4*)	110 (*9*)

Notes to Table 1:

(*1*) None survived fumigation.

(*2*) Colonial Sugar Refining Co. of Australia.

(*3*) Bureau of Sugar Experiment Stations, Queensland, Australia

(*4*) Collection included *S. robustum* and *S. spontaneum*.

(*5*) In addition there are 5 clones of *S. robustum* in HSPA or World Collection.

(*6*) Through cooperation of the Proefstation Oost-Java.

(*7*) Through cooperation of the HSPA.

(*8*) Collected primarily true seed of wild relatives, *S. robustum* and *S. spontaneum*—approximately 25 clones, under "Molokai" numbers remain in HSPA or World Collections.

(*9*) In addition there are approximately 25 clones of wild relatives under "Molokai" numbers in the HSPA or World Collections.

Saccharum officinarum

There are no commercial plantings of sugar cane in the New Guinea area. However, members of the cultivated species *S. officinarum* are found wherever the natives rely on subsistence gardening for their source of food. Subsistence agriculture is the rule throughout the area, the only exceptions being among more civilized societies in the immediate vicinity of the major centers such as Port Moresby, Lae, Rabaul, Hollandia, etc.

Canes belonging to the species *S. officinarum*, also known as "noble" canes, are grown by the natives for chewing purposes only and form a traditional portion of the diet. The relative importance of sugar cane in the native diet varies greatly from village to village and from district to district. In general, it is more important above 3000 feet in the highlands than in the lowlands. The percentage of sugar content in the juice of noble canes is generally lower in canes growing in the lowlands than in those growing in the highlands. Canes in the lowlands grow rather succulently, but, in the more temperate environments of the highlands, they grow more slowly and are usually sweeter. Because of the cooler climate and denser native population in the highlands, food is more difficult for the natives to obtain and their caloric needs are higher. These factors lead to more extensive culture of sugar cane and explain its relatively greater importance in the diet of the natives in the highlands.

The range of distribution of individual clones of *S. officinarum* varies greatly. Some clones were found widely distributed—from Manokwari, Dutch New Guinea, to New Britain and the Solomons. Other clones had a less extensive distribution, and some were seen only in a single village. One of the most widely distributed clones of *S. officinarum* was that collected as 57 NG 158 at Manokwari, Dutch New Guinea. This same cane was seen near Wewak, Madang, Rabaul and on Guadalcanal.

Saccharum robustum

The following discussion of *S. robustum* is subdivided by location groups. While not taxonomically established, such a breakdown is convenient from the standpoint of gross morphology and, in some cases, cytological data. Following a discussion of the type and similar forms, the other groups, tentatively included in *S. robustum*, will be discussed under the headings: Wau-Bulolo area, Markham-Ramu area, Sepik River area, Highlands area, and the New Britain-Solomon area.

No claim is made that the forms of *S. robustum* discussed under the various headings are distinct groups, as there is considerable overlap of similar forms in New Guinea. However, for the benefit of sugar cane breeders, the writers feel it desirable to present the picture as it appears at the present time, based on what they know and what they have observed. When material from the collections of cuttings and seed becomes available for cytogenetic and taxonomic studies in future years, a more scientific clarification of this complex group of plants may be formulated.

The Typical Form

The type of *S. robustum* is 28 NG 251, a clone collected in 1928 along the banks of the Laloki River near Port Moresby (1, 3). In its natural habitat this form grows on alluvial banks and bars along the Laloki River between the river's edge

Figure 4. S. robustum on the banks of the Laloki River, near where the type 28NG251 was collected in 1928.

and the jungle (Figure 4). It forms a dense thicket, with stalks 1¼″–1¾″ in diameter reaching to a height of about 20 feet. This form is not usually found along the river where it passes through open country. On stabilized banks, the jungle gradually encroaches and takes over.

Prior to the 1957 expedition, clones similar to 28 NG 251 were collected in 1928 on the Fly River and the Kemp Welsh River (Rigo), and in 1951 further collections were made on the Laloki River (2). All of these clones so far counted are reported to have a chromosome number of $2n=80$*. The 1928 expedition collected 28 NG 218 on the Sepik River near Ambunti, and while this clone is somewhat similar in appearance to the type, it is softer and sweeter. Its chromosome number is $2n=70$, which indicates that 28 NG 218 may be of hybrid origin.

In the course of the 1957 expedition, our knowledge of the distribution of forms similar in gross morphology to 28 NG 251 was considerably broadened. Such forms were found on the lower tributaries of the Markham River, along tributaries of the Sepik River and on the main river itself, along the lower Ramu River, and along smaller rivers in the vicinity of Popondetta, Madang, Awar, Wewak, Dagua, Aitape, Hollandia and Manokwari** (Figure 5). In Papua, they were seen near the Mekeo, and on the Brown River near Port Moresby. Similar forms were also seen near Rabaul, on Buka Island, and on Guadalcanal. In all cases, the forms were found in an ecological niche similar to that along the Laloki River where the type was found. Further taxonomic and cytological studies will determine if clones from these various areas can be correctly grouped with the type.

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* Unless otherwise noted, chromosome counts are as reported by Dr. Sam Price, USDA, (7) or in personal communications.

** Nishiyama et al (5, 6) has reported $2n=80$ for four clones of *S. robustum*, collected during WW II from somewhere on the Vogelkop Peninsula. These probably came from the vicinity of Manokwari or the Momi-Ransiki area where the Japanese agricultural projects were centered.

Figure 5. S. robustum in its typical environmental niche along the Gogol River near Madang.

The Wau-Bulolo Area

In general, the Wau-Bulolo group of *S. robustum* is composed of canes less robust than the typical form. They have a shorter tassel and smaller stalk diameter; the leaf sheath has more pubescence and is more clinging. Stalk diameter is usually ½″–1″, and the tassels are intermediate in appearance and size between those of typical *S. robustum* and *S. spontaneum*. These forms grow in relatively open situations along rivers and streams at an elevation of 1500–3000 feet.

The Wau-Bulolo group was first sampled in 1937 (4), and similar forms were collected in 1951 between Bulolo and Lae (2). The 1937 expedition also collected similar forms along the Francisco River. All of the clones in this group which have been studied cytologically have a chromosome number of $2n=60$, except a few which are in the range of $2n=63$–73 (7).

In the course of the 1957 expedition, the Wau-Bulolo area and the area along the Bulolo-Lae road (Snake River) were resampled (Figure 6). Similar forms were also collected near Garaina on a tributary of the Waria River, at an elevation of 2400 feet. There is considerable variation, both genetic and environmental, among the clumps found in these areas. The authors did not see any wild *Saccharum* in the Wau-Bulolo area other than the forms mentioned above which were provisionally placed in *S. robustum*.

Markham-Ramu Area

The Markham river flows southeast into the Huon Gulf near Lae. The lower Ramu River, after it leaves the highlands, flows northwest and finally north into the Pacific near the mouth of the Sepik River. Both of these valleys are wide, and the divide which separates the watersheds, somewhere in the vicinity of Gusap, is barely perceptible. The elevation of this broad divide is approximately 1600 feet. Below this elevation and except for the dense rain forest and jungle near the

Figure 6. S. robustum, of the Wau-Bulolo group, along the Snake River.

mouths of these rivers, the vegetation is mainly that of open grassland and savannahs. It is the *S. robustum* in this area which will be considered in this section.

Previous collection of wild canes in this area was limited to the 1937 expedition which stopped at Kaiapit (elevation 800 feet) for an hour (4), and to the 1951 expedition which operated for several days in the lower Markham as far up as Nadzab (2). The two Kaiapit clones which have been counted are $2n=60$ (7). The 1951 collections from the vicinity of Nadzab fall into two categories, $2n=60$ and $2n=80$.

In 1957, forms of *S. robustum* similar to the type were seen and collected near Lae, on tributaries of the lower Markham and on the lower Ramu and its tributaries, where the typical ecological niche was present. The lower Ramu was visited in the Aiome-Atemble area. However, in the open grassy flood plains, the predominant *robustum* is similar to the Wau-Bulolo type. This was seen at Gusap (elevation 1600 feet) and at Dumpu (elevation 800 feet), and in the Nadzab-Erap region of the lower Markham River. In each of these cases it was associated with *S. spontaneum*.

In the open flood plain of the Markham River, near Nadzab and Erap, there appears to be a great conglomeration of forms. There is the typical form in its usual habitat, the Wau-Bulolo form, and even some highland forms. This picture is further complicated by the presence of *S. spontaneum* and the possibility of interspecific hybridization.

Sepik River Area

The lower Sepik River flows easterly in the area between the Dutch border, near Green River, and the sea, a distance of about 250 miles by air and several times longer by boat, in the course of which the fall of the river is only about 230 feet. Its width varies between 300 yards and a mile. In this area, particularly below the mouth of the Yellow River, it flows through relatively flat terrain with

Figure 7. The red-fleshed form of S. robustum on the banks of the Sepik River near Pagwi.

a wide flood plain. Behind the banks of the river is usually either forest or sago swamp. Further back, one finds an undulating plain, forest interspersed with grassland and sago swamps, and the many tributaries of the Sepik.

Travelling by seaplane, the 1928 expedition stopped briefly on the Sepik near the Dutch border, at Ambunti, and at Marienberg near the river's mouth (1). Near Ambunti they collected, as *S. robustum*, two canes, 28 NG 218 and 28 NG 219. The original shipment of the latter did not survive and was replaced by two different but nearly identical canes, 28 NG 219 and 28 NG 219A, each with a chromosome number of $2n=60$ (7). These are representatives of the so-called "red-fleshed" *robustum*, *S. robustum* forma *sanguineum* Grassl (Figure 7). The other clone, 28 NG 218, is morphologically somewhat similar to the type species, 28 NG 251, but has a chromosome number of $2n=$ [illegible] and is softer and sweeter. It is likely that 28 NG 218 represents a chance hybrid involving a noble cane rather than what appears to be the typical form of *S. robustum* found on the tributaries of the Sepik River and occasionally on the river itself.

As a result of the 1957 observations in the Sepik area, *S. robustum* forma *sanguineum* (similar to 28 NG 219) would seem to be the predominant wild cane along the lower part of the main river. It was seen in the 40-mile stretch downstream from Ambunti to Pagwi, and near Angoram. How far it extends above Ambunti is uncertain, but reports of various patrol officers and others suggest that it occurs up to about the mouth of the Yellow River. This is approximately the point above which the Sepik follows a more fixed course and where its flood plain is relatively narrow*. The red-fleshed *S. robustum* is found on the river banks and on the flood plain where, for as much as six months of the year, the

* A. W. Herre [illegible] of *S. robustum* from the Sepik River on May 15, 1928, about which he remarks that it covers tens of thousands of acres along the Sepik River [illegible] unknown distance.

Figure 8. Native children chewing the succulent upper joints of the stalk of the red-fleshed form of S. robustum.

flood water level may cover the roots. It is found not only in a narrow band between the jungle and the river, but in broad expanses of flood plain where the jungle has not been able to encroach on the dense stands, presumably because the jungle plants prefer better drainage. It should be pointed out, however, that *S. robustum* was never seen growing in stagnant water; wherever the roots were covered by water, the water was moving.

It was particularly interesting to find that the natives commonly chewed, for refreshment, the top succulent joints of the stalks of the red-fleshed *robustum* (Figure 8). They selected the recumbent stalks which lay in the water of the river with their leafy top portions above the surface. When the leaves and rind are peeled off, the top 20–30 inch portion of the stalk is very juicy and succulent. This is the only area so far discovered where the natives habitually chew the stalk of a truly wild *Saccharum*.

The typical form of *S. robustum* (similar to 28 NG 251) was seen along tributaries of the Sepik, and occasionally on the main river (Figure 9). Under the latter conditions it was usually growing in better-drained situations where the flood waters covered the roots for only relatively brief periods. It was usually seen in narrow bands between the rivers and the jungle.

In the course of the 1957 expedition, the lower Sepik was visited twice. At the time of the first visit, April 3 to 10, the typical *S. robustum* was in full flower, while the tassels of the red-fleshed form were just beginning to emerge from the boot. When the area was revisited between June 6 to 11, the typical form had finished flowering and the seed had blown, while the red-fleshed form was in full flower. The earlier visit was made immediately following the period of peak flood. By the time of the second visit, the river had fallen 3 to 5 feet, and the exposed banks were covered with a turf of seedlings of *S. robustum*.

Figure 9. The typical (yellow) form of S. robustum along the Screw River, a tributary of the Sepik River, near Maprik.

On the Ramu River, at Atemble, the typical form of *S. robustum* was predominant, as might be expected since its appropriate ecological niche was present (Figure 10). Below Atemble, the Ramu enters an area similar to that of the lower Sepik, providing a situation where the red-fleshed *robustum* might be found, but so far it has not been possible to collect there.

Highlands Area

The so-called highlands area of New Guinea extends from Aiyura and Kainantu on the east as far as the Wissel Lakes area of Dutch New Guinea. It is a mountainous region with peaks rising more than 14,000 feet above sea level. There are numerous arable valleys with a base elevation of 4000–6000 feet, some of which are 10 miles wide and 40 to 60 miles long. The highlands have a temperate climate and are rather densely populated.

The 1937 expedition first sampled *S. robustum* from the highlands area on both the Ramu and Purari watersheds in the vicinity of Kainantu (4). The 1951 expedition worked extensively in the vicinity of Aiyura, Kainantu, Goroka, the Chimbu region, Mt. Hagen and Mendi (2). Collections were made of *S. robustum* both as cuttings and as true seed. Several of the clones collected had chromosome numbers of $2n = 156–164$, and one, 51 NG 106, was $2n = 194$ (7). In the field, these were all collected as examples of the more attractive types. The more common forms, as well as all the seedlings which have been counted, have a chromosome number of $2n = 80$ (with the exception of Mol. 5715, Kainantu, 1937, $2n = 84$). The opinion expressed by the members of the 1951 expedition, the senior author included, was that, except for the Kainantu area, *S. robustum* did not appear indigenous to the

Figure 10. The typical form of **S. robustum** along the banks of the lower Ramu River at Atemble near Aiome. The moist silty spots along the river banks were covered with a turf of **S. robustum** seedlings.

highlands (2). Its prevalence throughout the area was attributed to its usefulness as a building material, particularly for garden fences—where it germinates and grows into hedgerows and is later spread by man and erosion until its distribution has come to seem almost natural (Figures 11 and 12).

The 1957 expedition collected in the highlands area near Nondugl (Wahgi-Purari drainage), Baiyer River (Sepik drainage), Tari (Kikori drainage), Telefomin (Sepik drainage), and the Wissel Lakes. While the observations of the 1951 expedition were substantially correct with regard to the location where highland *S. robustum* appeared indigenous, the Wahgi valley, Baiyer River, Tari and the Wissel Lakes must now be added to the Kainantu area. Undoubtedly other similar areas will be found. The fact remains that man has so greatly extended the distribution of *S. robustum* in the highlands that it is now found existing in many locations outside of its natural environment. Its natural habitat in the highlands is essentially the same as that of *S. robustum* in the Wau-Bulolo area, i.e., in relatively open situations on well-drained flood plains where there is ample moisture, usually along or near streams. In appearance, too, the highland *robustum* is quite similar to the *robustum* of the Wau-Bulolo area. Because the chromosome number of those clones which have been counted is $2n=80$, the highlands *robustum* must be tentatively considered separate from the Wau-Bulolo group ($2n=60$) in spite of morphological similarity (7).

It should be pointed out that the forms of *S. robustum* present in the vicinity of Tari and in the Wissel Lakes seemed to be somewhat different in gross appearance from the common forms in the more eastern highlands. This remains to be verified when the canes can be grown side-by-side. The Tari canes appeared to

Figure 11. A fence being made of *S. robustum* near Goroka, in the highlands.

have a shorter and bushier tassel than the typical highlands form, while those from the Wissel Lakes had a wider and shorter leaf. Both types have less sheath pubescence than the typical highlands form.

In the course of the 1957 expedition's travels in the highlands, several exceptional clones were collected on the presumption that they were either complex hybrids or would turn out to be plants with a high chromosome number. The only clone of this type so far studied cytologically, 57 NG 131, has borne out this presumption. It is probably a complex hybrid, possibly a generic hybrid, involving elements not known at present. In the case of 51 NG 88 ($2n = 161$–164) and 51 NG 106 ($2n = 193$–194), it is suspected that *Miscanthus floridulus* (Labill.) Warb. may be involved in part. The fact that in every case these odd canes have been found growing in old fences or in abandoned gardens suggests that they are not a part of a wild population but owe their existence to man's care and selection. That odd canes of this nature are widespread in the highlands can be expected. The junior author now considers that the collections (No. 11778 and 11374) by L. J. Brass of the Archbold Expeditions, from the highlands of Netherlands New Guinea, are similar forms. Such complex hybrids are not forms of *S. robustum*, but are placed under this species as a matter of convenience.

New Britain-Solomons Area

Previous collections from New Britain were made by the 1937 expedition (4). Some forms of *robustum* from this island are somewhat unique in appearance but nevertheless fall within the general concept of the species. Chromosome counts of much of this material show $2n = 100$–112, but, as explained by Price, these are seedlings with the same clone as female parent. It is suspected that this particular clone is of complex hybrid origin and not a typical *robustum*. This same clone also contributed to seedlings with aberrant chromosome numbers of $2n = 86$–92 and $2n = 160$–163, all of which are listed under New Britain *robustum*. However, all of

Figure 12. An old **S. robustum** fence, grown up into an impenetrable hedgerow, near Goroka in the highlands.

the clones counted from the 1937 collections on the Toriu River, New Britain, are $2n = 80$.

The 1957 expedition collected only very briefly near Rabaul. Typical *robustum*, similar to 28 NG 251, was seen on the Keravat River. On Buka Island, off the northern tip of Bougainville, and also on several rivers on Guadalcanal, the typical form was seen. It appears that most of the rivers and streams on the islands of the Bismark Archipelago and in the Solomon Islands are not of the kind where one expects to find much *robustum*. They follow fixed courses through dense jungle and thus do not usually provide the proper ecological niche for *robustum*. Again, cytological study of the collections made in 1957 will help to clarify the taxonomy of the *robustum* of this area.

Saccharum spontaneum

Previously *S. spontaneum* had been reported from the Port Moresby area (1, 2), near Rigo, Milne Bay, and the lower Markham, and near Goroka. It has also been reported from the Mamberamo River in Dutch New Guinea, but photographs of the plant showed that it is almost certainly *S. robustum*. Herbarium specimens have been collected from Cape Gloucester, New Britain. Reports of this species (Brass numbers 11374 and 11778) from the highlands of Netherlands New Guinea by the junior author are now believed to have been errors of identification (3).

There is some question as to whether this species is indigenous or a fairly recent introduction. A further study of the Port Moresby area in 1957 indicated

Figure 13. S. spontaneum in the savannah terrain near Port Moresby.

that *spontaneum* is either indigenous there, or has been there a long time. It is found wherever its particular environmental requirements are met. In this rolling savannah terrain, these ecological niches are scattered, but wherever a well-drained situation with ample moisture is found in open country, *S. spontaneum* is sure to be found (Figure 13).

In the lower Markham valley, and also in the Mekeo and Popondetta areas, there are vast expanses of *S. spontaneum*. In 1957, it was also seen near Garaina, Gusap, Dumpu on the Ramu River, at Awar, and at Angoram on the lower Sepik River. Small patches seen on Biak Island and near Rabaul were deemed recent introductions. Observation of *S. spontaneum* near Goroka in 1951 could not be confirmed in 1957 because the area concerned is now growing coffee. This was the only case in New Guinea where *S. spontaneum* has been reported at an elevation of more than 2500 feet and quite likely represented a chance colony far out on the perimeter of the present distribution of this species.

S. spontaneum was also found to be widespread on Guadalcanal, again saturating its specific ecological niche in the undulating grassland plains. This represents a new extension to the known distribution of this species, as it had previously been reported only as far to the southeast as Milne Bay.

It is logical to anticipate that *S. spontaneum* will be found to be even more widespread in the New Guinea area, in both Australian and Dutch territories, providing the proper environmental conditions are present.

Saccharum edule

The edible-tassel form of sugar cane, *S. edule*, is a cultivated species found associated with *S. officinarum* in the native subsistence gardens of the New Guinea

Figure 14. Flower heads of **S. edule**, the edible-tassel species, in a native market in Lae. Chewing canes are also seen among the local produce.

area (Figure 14). In this species, the tassel does not emerge normally except in rare instances. Instead it forms a cauliflower-like mass which is boiled or baked in the sheath and eaten as a vegetable.

Several specimens of *S. edule* were collected by the 1928 expedition (1). The 1937 expedition noted a normal flower on an *edule* and collected the fuzz. The fuzz was germinated at the HSPA Quarantine Station on Molokai, but all of the several seedlings which resulted were extremely weak and survived for only a few weeks. The 1951 expedition noted many clones of *S. edule* and their similarity to *S. robustum* (2).

The 1957 expedition collected a number of specimens of *S. edule* in order to study their chromosome numbers in an effort to clarify the relationships of this curious species. Morphologically they seem to be most closely related to *S. robustum*. The stalks, usually ¾″–1¼″ in diameter, are relatively dry and high in fiber. One case of a normal tassel on an *edule* was noted near Madang. The tassel was too young to take for seed but in conformation it was similar to a tassel of *S. officinarum*. However, the large florets and the many long callus hairs were reminiscent of some of the non-typical forms of *S. robustum* from the highlands or Wau-Bulolo areas.

CONCLUSIONS

As the New Guinea area is more thoroughly canvassed for sugar cane germplasm, it becomes increasingly probable that the center of origin of the species *S. officinarum* is somewhere in this area. The greatest number of clones of *S. officinarum* are found here as well as a large number of forms of what appears to be the nearest wild relative (*S. robustum*). Whether *S. officinarum* originated from the gradual selection out of wild populations of softer and sweeter canes, or from wild canes brought into cultivation for fences or other uses, has not been deter-

mined. There remains the possibility that somewhere a place will be found where *S. officinarum* or similar types do exist as wild canes.

While there have been several major expeditions in the New Guinea area to collect breeding material of *S. officinarum* and its wild relatives, the job is not yet finished. It appears that further exploration and collection would be profitable particularly in the following areas:

1. The lower Sepik River, the lower Ramu River, and their major tributaries, for additional forms of *S. robustum*.

2. The Vogelkop Peninsula of Dutch New Guinea for representatives of *S. officinarum* and *S. robustum*. The cultivated clones from this area collected by the 1957 expedition were unusually handsome, but only a small sample could be gathered from two locations.

3. The Tanah-Merah area on the Digoel R. in Dutch New Guinea, reported to have a rich flora of *Saccharum*.

4. The Baliem Valley in Dutch New Guinea, a highlands area supporting a native population of good farmers and reported to have many chewing canes.

5. The Tage and Tigi Lakes area, in the Wissel Lakes region, reported to have a rich flora of chewing canes.

6. The Memberamo River, and its major branches, the Idenburg and the Rovffaer, for both wild and cultivated *Saccharum*.

Further studies of breeding value, and of cytology and taxonomy, of canes now in our collections may suggest other areas of particular interest.

ACKNOWLEDGMENT

To name all the individuals who helped to make the 1957 USDA Sugar Cane Expedition a success would be a physical impossibility. Without exception, administration officials, and their agricultural and forestry departments, went out of their way to be helpful. Thanks to their whole-hearted assistance and cooperation, both as individuals and as members of organizations, the expedition achieved its objective.

LITERATURE CITED

1. Brandes, E. W. 1929. Into primeval Papua by seaplane. Nat'l. Geogr. Mag. 56:253–332.
2. Buzacott, J. H. and C. G. Hughes, 1951. The 1951 cane collecting expedition to New Guinea. Queensland Bur. Sugar Expt. Sta., Cane Growers' Quart. Bul. 15:35–72.
3. Grassl, C. O. 1946. *Saccharum robustum* and other wild relatives of "noble" sugar canes. J. Arnold Arb. 27:234–252.
4. Lennox, C. G. 1938. Sugar cane collecting in New Guinea during 1937. Haw'n. Planters' Rec. 42:235–246.
5. Nishiyama, I., I. Yamada, and N. Kondo, 1942. Studies on the sugar cane. I. Karyological observations on wild and cultivated sugar canes. (Japanese with Eng. sum.). Report Kihara Inst. Biol. Res. (Seiken Ziho) 1:10–16.
6. Nishiyama, I., K. Furusato, I. Yamada, and N. Kondo, 1947. Studies on the sugar cane. IV. Chromosome numbers of wild sugar canes in Micronesia. (Japanese with Eng. sum.). Report Kihara Inst. Biol. Res. (Seiken Ziho) 3:63–67.
7. Price, S. 1957. Cytological studies in *Saccharum* and allied Genera. II. Geographic distribution and chromosome numbers in *S. robustum*. Cytologia 22(1):40–52.
8. Stone, O. C. 1876. Letter from Papua. The Queenslander, Brisbane (Feb. 12, 1876).

APPENDIX A

Collections of *S. officinarum*

Clone	Location	Elevation (feet)	Native Name and Remarks
57 NG 6	Garaina, Waria R. Drainage	2400	Su-Su
7	" " " "	"	Otuna
8	" " " "	"	Desogo
9	" " " "	"	Pubama
13	Wantoat, Markham R.	3700	Wai-It
14	" " "	"	Ta-Map-Ma
15	" " "	"	Wango-Wango
16	" " "	"	Kan-Tam-Bum
17	" " "	"	Komam
18*	" " "	"	Maman
26	Menyamya, Tauri R.	3600	Kung-Ga. May be same as 57 NG 15.
29*	Kaisenik, near Wau	3400	U-Ur-O
30	" " "	"	Yo-Ru
31	" " "	"	Korayabi
32	" " "	"	Kamayina
33*	" " "	"	Tob
34	" " "	"	Kail
35	" " "	"	Wa-Lek
36	" " "	"	Lua-Vi
37	" " "	"	Gangalu
38	" " "	"	Gamarevi
39*	" " "	"	Tambu
41	" " "	"	Lousanga
42*	" " "	"	Kuaro
43	" " "	"	Yel-Uk
48	Patep #2 Bulolo-Lae Rd.	2500	Maia
49	" " " "	"	Bo-Ba-Ga
50	" " " "	"	Ketum-Bok
51	" " " "	"	Ketima
52	" " " "	"	Eneba
53	" " " "	"	Tam-Bi
57	Wagum, Gogol R., near Madang	200	Au
58	" " " " "	"	Dui
59	" " " " "	"	Gum
60	Madang	25	Mal
61	"	25	Ma-Mal
62	"	25	Dou
63	"	25	Karan. Also seen in Sepik Dist.
64	"	25	Waip
65	Mandi, near Wewak	25	Yemben
66	" " "	25	Tu-Ra
67	" " "	25	Dum-Ai-Au
68	" " "	25	Deg-Alem. Check with 57 NG 61.
69	" " "	25	Sakansu
70	" " "	25	Supol
71	Mandi, near Wewak	25	Vai-Wa
72	" " "	25	Vai-Wa striped form of 57 NG 71.
73	" " "	25	Dum-Ai-Au. Self-colored form of 57 NG 67 (light)
74	" " "	25	" " " (dark)
75	" " "	25	Mung-Ar
76	" " "	25	Roke
77	" " "	25	Ara-Maia. Pithy. Natives say this is a primitive chewing cane, kept only for legend and ceremonies.
78	" " "	25	Kenapai
85*	Bainyik, near Maprik, Sepik drainage	550	Kangui
86*	" " " " "	"	Kwangsingui
87*	" " " " "	"	Galangui
88	" " " " "	"	Malapele
89*	" " " " "	"	It-Te-Huango
90*	" " " " "	"	Duangelit
91*	" " " " "	"	Da-Seeb
92	Ambunti, Sepik R.	100	Gui

APPENDIX A—Continued

Clone	Location	Elevation (feet)	Native Name and Remarks
57 NG 94*	Yenchangai, near Ambunti Sepik R.	100	Manui
95	" " " " "	"	Mai-Im
96	Lapungai, near Ambunti, Sepik R.	"	Kalam
97*	" " " " "	"	Wabi
98*	" " " " "	"	Kamingwai
99	" " " " "	"	Patel
100*	Japandai, near Ambunti, Sepik R.	"	Sangi
101	" " " " "	"	————
102*	Yenchangai, near Ambunti, Sepik R.	"	Wabi
106	Yambi, near Maprik, Sepik drainage	300	————
107*	Supari, near Maprik, Sepik drainage	300	Ai-He-Pela
108	Telefomin, near Maprik, Sepik drainage	4800	Ko-Ri
109*	" " " " "	"	Teneb
110	" " " " "	"	Afakulap. Very similar to 57 NG 109.
111	" " " " "	"	Afaim.
112*	" " " " "	"	Fairi
113	" " " " "	"	Futuru
114	" " " " "	"	Doong. Also seen at Baiyer R.
115	" " " " "	"	Aliksok
116	" " " " "	"	I-Lel
117	" " " " "	"	Uruk. Very large stalk diameter.
118*	" " " " "	"	Ko-Ta-Su-Nok
119	" " " " "	"	Freem
120	Telefomin, Sepik drainage	4800	Freem. Self-colored form of 57 NG 119.
121*	" " "	"	Mi-On
123	Lumi, Sepik drainage	1800	Boi-U
124*	" " "	"	Tandimali-E
125	" " "	"	Nafli or Yali
127	" " "	"	Makubu
130*	" " "	"	————
135	Baiyer River, Sepik drainage	4300	Ba-Ga. Double eyes.
136	" " " "	"	Keruma
137	" " " "	"	Kogla. Check with 51 NG 108.
138	" " " "	"	Mugiump. Check with 51 NG 110
139	" " " "	"	Ba-Ga. Color variant of 57 NG 135.
140	" " " "	"	Ki-Awaiya
141	" " " "	"	Ay-Gligim
142	" " " "	"	Ki-Awaiya. Color variant of 57 NG 140.
143	" " " "	"	Maui
144	" " " "	"	Dim
146	Tari, Kikori drainage	5200	Awa
147	" " "	"	Semboo
148	" " "	"	Igibu
149	" " "	"	Neko
150	" " "	"	Wabena
151	" " "	"	————. Not a favorite chewing cane.
152	" " "	"	Wabena. Same name as 57 NG 150, but different cane.
155	Manokwari, D.N.G.	100	————
156	" "	"	————
157	" "	"	Hi-Crom
158	" "	"	Hangwoi. Widely distributed cane
159	" "	"	Hi-Crom. May be striped form of 57 NG 157.
160	" "	"	Sempeo
161	" "	"	Not pure noble (?) May be Japanese introduction.
162	" "	"	————
163	" "	"	————. Same as 57 NG 162.
165	" "	"	————
166	" "	"	————
167	" "	"	————

Clone	Location	Elevation (feet)	Native Name and Remarks
57 NG 169	Manokwari, D.N.G.	100	————. Brought from Macassar
171	Malanubaru, Sorong, D.N.G.	100	Bisi-Madak
172	Ransiki, S. of Manokwari,, D.N.G.	"	Ransiki was not visited, but these
173*	" " " " "	"	clones were received by messenger
174	Anggi Lakes, near Ransiki, D.N.G.	5500	————Very large stalk diameter
175	Malanubaru, Sorong, D.N.G.	100	Bisi-Belah
176	" " "	"	Bisi-Galamu
177	Tanjungcassowari, Sorong, D.N.G.	10	Kamainsimbur
178*	" " "	10	Kamantanenem
180	Enarotali, Wissel Lakes, D.N.G.	5700	Kigite
181	" " " "	"	Mutii
182	" " " "	"	Mus
183	" " " "	"	Tua-Tua
184	" " " "	"	Ajai
185	" " " "	"	Teto
186	" " " "	"	Pogie
187	" " " "	"	Deke-Deke
188	" " " "	"	Kugube
189	" " " "	"	Tukiai
190	" " " "	"	————
191	" " " "	"	Gobei
192	Kene-Apa, Wissel Lakes, D.N.G.	"	Kumati
195	Merauke, D.N.G.	50	Kapatu
196	" "	50	Mbur-Jaba
197	" "	50	Suba-Jaba
198	" "	50	Suba-Papes
199	" "	50	Wahoek-Jade
200	" "	50	Kasabod
203	Hollandia, D.N.G.	50	Ju
204	" "	50	Ju-Wak-Leu
205	" "	50	Wa-No-Kou
206	" "	50	Ma-Le-U. Self-colored form of 57 NG 204 (?)
207	" "	50	Of-Ai-Ju
209	Dumpu, Ramu R.	800	Om
210	" " "	800	Kwis
212	" " "	800	Ogoro
213	" " "	800	Be
214	" " "	800	Mom
215	Aiome, Ramu R.	350	Indupin
216	" " "	350	Comus. Hairy stalk.
218	Bainyik, near Maprik, Sepik drainage	550	Duangelit. Same as 57 NG 90 (?)
219	" " " " "	550	Kangui. Same as 57 NG 85 (?)
220	" " " " "	550	Tehebnucal
221	" " " " "	550	Kangui. Same as 57 NG 85 (?)
222	" " " " "	550	————
223	" " " " "	550	Desam
224	" " " " "	550	Tehebnucal. Color variant of 57 NG 220.
225	" " " " "	550	Tehebnucal. Striped form of 57 NG 220.
226	" " " " "	550	It-Te-Huango. Same as 57 NG 85 (?)
227	" " " " "	550	Tehablo
228	" " " " "	550	Desuang
229	Japanout, Sepik R. near Maprik	100	Kalamaram
234	Kerevat, New Britain	150	————
235	" " "	150	————
236	" " "	150	————
237	" " "	150	————
239	" " "	150	————
240	Betikama, Guadalcanal, BSI	100	Sele or Toru
241	" " "	100	Malasese
242	Ilu, Guadalcanal, BSI	100	Orfu-Buru (Brought from Malaita)
243	" " "	100	Orfu-Sari (Brought from Malaita)

APPENDIX A—Concluded

Clone	Location	Elevation (feet)	Native Name and Remarks
57 NG 244	Nggela, Florida Is., BSI	10	————
245	" " " "	10	Flesh striped like rind
251	Hangan, Buka Is.	100	Amoe
252	" " "	100	Tohu
253*	Kerevat, New Britain	150	————
254	Near Kerevat, New Britain	50	Mandar #2
256	Epo, near Mekeo	100	Muu Muu
257	" " "	100	Oe. Badila type.
258	" " "	100	Kipili
259	" " "	100	Egepio
260	" " "	100	Imau-Opo
262	Popondetta	100	Gobe

* Failed to survive in quarantine.

APPENDIX B

Collections of *S. robustum*

Clone	Location	Elevation	Remarks
57 NG 1	Between Laloki and Brown Rivers, near Port Moresby	50	Stream bank
2	Between Laloki and Brown Rivers, near Port Moresby	50	" "
3	Brown R., near Port Moresby	50	" "
10	Burui, Sepik R.	250	Collected in Lae Botanical Garden
11	Ramu R., trib. of Markham R.	400	Stream bank
12	Between Erap R. and Ramu R., Markham Road	400	" "
21	Wantoat, Markham drainage	3700	In garden fence
22	" " "	3700	Stream bank
24	" " "	3700	" "
44	Snake R., on Wau-Bulolo Rd.	2000	" "
54	Madang	50	" "
55	"	50	" "
56	Gogol R., near Madang	200	" "
83	Maprik, Sepik drainage	500	" "
93*	Ambunti, Sepik R.	100	River bank. Red form.
103*	Lapungai, near Ambunti, Sepik R.	100	" " " "
104*	" " " " "	100	In garden. Yellow form.
105	Sepik R., near Maprik	100	River bank. Red form.
131	Nondugl, Purari drainage	5700	Garden fence. Hybrid (?)
132	" " "	5700	" " "
133	" " "	5700	" " "
134	" " "	5700	" " "
145	Tari, Kikori drainage	5200	" " "
153	" " "	5200	" " "
154	Wosi R., Manokwari, D.N.G.	100	Stream bank
168	Andai R., Manokwari, D.N.G.	20	" "
170	Bami R., Manokwari, D.N.G.	50	" "
193	Keneapa, Wissel Lakes, D.N.G.	5700	In garden. Hybrid (?)
194	Ara R., Wissel Lakes, D.N.G.	5700	Stream bank
201	Tami R., Hollandia	10	" "
202	Hollandia, D.N.G.	50	" "
208	Dampu, Ramu R.	800	River bank
217	Atemble, Ramu R.	100	" "
230	Pagwi, Sepik R. near Maprik	100	River bank. Red form.
231	Angoram, Sepik R. near Maprik	50	River bank. Yellow form.
232	" " " " "	50	River bank. Red form.
238	Kerevat R., New Britain	50	River bank.
246	Tenaru, Guadalcanal	10	Stream bank.
249	Honiara, Guadalcanal	10	In garden
250	Buka Is.	100	In garden
255	Epo, Mekeo	50	Stream bank
261	Popondetta	300	Stream bank

* Failed to survive in quarantine.

APPENDIX C

Collections of *S. edule*

Clone	Location	Elevation (feet)	Native Name and Remarks
57 NG 4	Garaina, Waria R. drainage	2300	Ti-I
5	" " " "	2300	Ti-I
19	Wantoat, Markham R. drainage	3700	Bi-Au-Sik
20	" " " "	3700	Gwa-Mege
27	Menyamya, Tauri R.	3600	Ko-A
28	" " "	3600	Ko-A
39*	Kaisenik, near Wau	3400	Tambu
40	" " "	3400	Gui-Wi
45	Patep #2, Bulolo-Lae Rd.	2500	Nun-Ga
46	" " " "	2500	Tu-Bune
47	" " " "	2500	Balende
79	Mandi, near Wewak	25	Dana
80	" " "	25	Subum
81	" " "	25	Merip
82	Dagua, near Wewak	50	Gonuba
84*	Ulupu, near Maprik, Sepik drainage	500	Kuigato
122*	Telefomin, Sepik drainage	4800	Asaup
126	Lumi, Sepik drainage	1800	Lau-I
128	" " "	1800	Poola
129	" " "	1800	Yilbil
164	Manokwari, D.N.G.	100	Teboe Telor
179	Biak, D.N.G.	200	Liling or Teboe Ikang
195	Merauke, D.N.G.	50	Kapatu
211	Dumpu, Ramu R.	800	Ken
233	Angoram, Sepik R.	50	Singangan
248	Takamboro, Guadalcanal	50	———

* Failed to survive quarantine.

APPENDIX D

Seed Collection of *S. robustum*

Collection No.	Notes
566	Near Lae about 100 ft. elevation.
571	From edge of Bubu River near Garaina, Morobe Dist. Elevation 2400 ft.
586	On the Yalu River (a tributary of the Markham) about 14 miles from Lae.
605	Edge of Korlte River near Menyamya (no germination). Elevation 3500 ft.
626	Along Snake River near Mumeng (about 21 miles from Bulolo on road to Lae). 2000 ft. elevation. (Large form).
627	*ibid.* (normal form in this valley). Coll. of mixed clones to be checked for influence of *S. spontaneum*). Elevation 2000 ft.
629	*ibid.* from clone 57 NG 44. Elevation 2000 ft.
631	From bank of Bigeas River about 10 miles North of Madang.
632	From bank of Gum River about 6 miles from Madang.
633	From bank of Gogol River about 24 miles Southwest from Madang.
642	From bank of Brandi River about 10 miles East of Wewak.
645	From near Dagua.
650	From near Bainyik.
668	Edge of Sepik River, 1 mile below Ambunti (yellow form).
669	In water of Sepik River between Pagwi and Ambunti. (More yellow than typical red form.)
686	Edge of stream at Telefomin, Sepik Dist. 4800 feet elevation (composite clones).
690	Upper Sepik River near Telefomin. Elev. 4600 feet.
697	Lumi (rare here but occasional clumps as if in old gardens). Elevation 1800 ft.
701	Tadji, 20 feet elevation (Sepik type, yellow, waxy, hairy 57).
713	In cult. at Nondugl (mottled stem and has Fiji disease, no germination). Elevation 5700 ft.
723	From Girua River about 7 miles from Popondetta. Coll. by Dr. D. E. Shaw (no germination).

APPENDIX D—Concluded

Collection No.	Notes
724	From old garden near Baiyer River. Elevation 3800 ft.
725	Common along bank of Baiyer River. 3800 feet elevation. (Highland type.)
733	Relatively short tassel form from swamp near Tari. Elevation 5200 ft.
734	Bushy tassel form called Kamba from near Tari.
737	Striped leaf form same as 57 NG 153 from near Tari. (No germination). Elevation 5200 ft.
741	From bank of stream at Kota Nica, Hollandia. (Flowering almost over May 2.)
742	*ibid.*
755	Jabau River near Kota Nica, Hollandia. (Mixture of clones.)
763	Edge of Andai River about 23 km. S.W. of Manokwari.
783	Near mouth of Ara River, Wissel Lakes. Called Parimo. (Similar to 57 NG 194). Elevation 5700 ft.
787	From Tami River, near Hollandia. (Same as 57 NG 201). No germination.
795	On bank of Ramu River at Dumpu. (Highland type.) Elevation 800 ft.
796	Edge of Ramu River at Dumpu. (Same as 57 NG 208). Elevation 800 ft.
801	Edge of Ramu River at Atemble (12 to 20 feet tall).
802	Edge of airstrip at Awar.
806	Bank of Sepik River at Pagwi. (Red form.)
807	Near Japanout Village on Sepik River opposite Pagwi. (Red form.)
808	*ibid.* (Red fleshed form.)
809	On bank of Sepik River below Pagwi. (Red fleshed form.)
812	Edge of Sepik River at Angoram. (Red fleshed form.)
818	Near Betekama on bank of Lunga River, Guadalcanal.

Note: Where not specifically noted, elevations are less than 500 ft.

APPENDIX E

Seed collection of *S. spontaneum*

Collection No.	Notes
555	Roadside between Laloki River and Brown River, near Port Moresby.
556	Roadside on Rouna Falls road about 9 miles from Port Moresby; (long-tassel type, many hairs on sheath). Elevation 800 feet.
557	*ibid*, (no hairs on sheath); 8 miles.
558	*ibid*, 15 miles from Port Moresby; 450 ft. elevation.
565	From Lae Botanical Garden originally from Saidor Coast near (E. of) Madang.
567	Open field near Cecil Hotel, Lae.
568	Busu Loop, Lae.
572	From edge of Bubu River near Garaina, Morobe Dist. (primitive form: Warner). Elevation 2400 feet.
573	On the escarpment at Garaina (intermediate: Warner). Elevation 2400 feet.
587	From between Erap River and the Rumu River about 350 feet elevation (Markham River drainage).
634	From edge of Gusap airfield. Elevation 1600 feet.
786	Open roadside on Biak (probably a recent introduction). No germination.
797	Edge of Ramu River at Dumpu (very common on gravel banks). Elevation 800 feet.
813	Low field near edge of Sepik River at Angoram.
819	Edge of roads and airfield at Honiara, Guadalcanal.
822	Roadside near Kokopo about 20 miles from Rabaul, New Britain Is. (Probably a recent introduction.)
831	Many acres along roadside near Epo (Mekeo).
832	Near airfield at Epo (Mekeo).
833	Near Epo (Mekeo). Only one large patch late flowering and somewhat intermediate between *S. spontaneum* and *S. robustum*.
835	Many hundreds of acres in grassy plains on sandy, well drained areas near Popondetta.

APPENDIX F

List of Andropogoneae Collected*

Dimeria ciliata Merr.
671 Telefomin, N. G.
Imperata cylindrica (L.) Beauv.
519 Ripple Creek near Bemerside, Ingham, Queensland, Australia
Imperata exaltata Brongn.
502 Sigatoka River, Fiji
532 Port Moresby, New Guinea
542 Brown River, N. G.
562 Lae, N. G.
570 Garaina, N. G.
601 Bulolo, N. G.
628 Village Patep #2, between Bulolo and Lae, N. G.
651 Dagua, N. G.
672 Telefomin, N. G.
Miscanthus floridulus (Labill.) Warb.
501 Common on hillside at Yako, Fiji
618 Wau (3900 ft.) no ger.
623 Above Wau on Edie Creek Road.
687 Telefomin (4800 ft.)
699 Lumi (native garden)
714 Nondugl (large tassel form)
716 Nondugl (short inflorescence ? disease)
735 Tari (waxy upright-blade form)
736 Tari (normal form)
779 Wissel Lakes (5700 ft.)
826 Native garden 16 miles W. of Honiara
Erianthus fastigiatus (Nees ex Steud) Hack.
593 Wantoat (3700 ft.)
615 Bulolo (2550 ft.)
617 Bulolo (2350 ft.)
Eulalia trispicata (Schult.) Henr.
576 Garaina, Morobe Dist.
652 Yambi, near Maprik
729 Baiyer River, N. G.
745 Hollandia Haven, N. N. G.
749 Sentani, N. N. G.
Eulalia leptostachys (Pilger) Henr.
594 Wantoat (3700 ft.)
603 Korlte River, Menyamya
621 Wau (no ger.)
638 20 miles in from Madang
657 Maprik
707 Nondugl
777 Enarotali (5700 ft.)
Pseudopogonatherum irritans (R. Br.) A. Camus
666 About 21 miles from Maprik on way to Pagwi
746 MacArthur Hill, Hollandia
Microstegium ciliatum (Trin.) A. Camus
658 Maprik (no germination)
Pogonatherum paniceum (Lam.) Hack.
606 Korlte River, Menyamya (no ger.)
619 Wau
622 Above Wau on Edie Creek Road (6300 ft.)
709 Nondugl
823 Rabaul, New Britain
827 Matanikan River, Honiara, Guadalcanal
Ischaemum aristatum L.
590 60 miles from Lae on Erap Road
654 Yambi
665 Maprik
693 Green River
719 Nondugl
781 Enarotali
Ischaemum muticum L.
825 20 miles west of Honiara

* Arranged according to Reeder, John R. The Gramineae-Panicoideae of New Guinea. Jour. Arnold Arboretum, Vol. XXIX, pp. 321–392. 1948.

Ischaemum digitatum Brongn.
553 10 miles above Rouna Falls
611 Korlte River, Menyamya
640 Bigess River near Madang
655 Yambi
659 Maprik
670 Telefomin
679 Ambunti, Sepik River
738 Tari (waxy form)
739 Tari (normal form)
756 Biak
815 Angoram, Sepik River

Apluda mutica L.
592 From between Erap and Rumu Rivers
637 About 20 miles from Madang
717 Nondugl
744 Hollandia

Hackelochloa granularis (L.) Kuntze
610 Korlte River, Menyamya

Hemarthria compressa (L.f.) R. Br.
776 Sorong (sandy beach)
785 Napan (sandy beach)
791 Hollandia (sandy beach)

Eremochloa ciliaris (L.) Merr. var. elata Reeder
653 Yambi, near Maprik

Rottboellia sp.
517 Stone River, Ingham, Queensland

Rottboellia rottboellioides (R. Br.) Reeder
512 Ingham, Queensland
524 Cairns, Queensland
539 Between Laloki and Brown Rivers
612 Wantoat
578 Garaina
625 Snake River, 17 miles from Bulolo on road to Lae.
793 Dumpu, Ramu River
800 Atemble, Ramu River

Ophiuros exaltatus (L.) Kuntze.
546 Near Rouna Falls
589 About 28 miles from Lae
646 Dagua
720 Nondugl
731 Baiyer River

Sorghum nitidum (Vahl.) Pers
510 Stone River, Ingham, Queensland
516 Elphinstone Pickett, Ingham, Queensland
520 Ripple Creek, Ingham, Queensland
525 Cairns, Queensland
526 Cairns, Queensland
530 Port Moresby
543 10 miles from Port Moresby on way to Rouna Falls
545 near Rouna Falls
563 Lae
574 Garaina
588 28 miles from Lae
595 Wantoat
607 Korlte River, Menyamya
620 Wau
649 Kagua
662 Maprik
702 Tadji
703 Tadji
721 Nondugl
730 Baiyer River
743 Hollandia (Gov. Hotell)
792 Ramu River at Dumpu
803 Awar
814 Sepik River at Angoram
830 Kerevat, New Britain I.
834 Popondetta

Sorghum laxiflorum F. M. Bailey
596 Wantoat
602 Korlte River, Menyamya
Sorghum plumosum (R. Br.) Beauv.
508 Ayr Airport, Queensland
Chrysopogon aciculatus (Retz.) Trin.
511 Ingham, Queensland
648 Dagua
(This species was seen at practically every airfield visited.)
Chrysopogon filipes (Benth.) Reeder
514 Gowrie Creek, Abergowrie, Queensland
521 Mulgrave River, Cairns, Queensland
Arthraxon hispidus (Thumb.) Makino
608 Korlte River, Menyamya
613 Wantoat
682 Telefomin
Capillipedium parviflorum (R. Br.) Stapf
537 Port Moresby
549 Rouna Falls
575 Garaina (awnless form)
636 Gusap
683 Telefomin
Capillipedium spicigerum S. T. Blake
522 Cairns, Queensland
540 Between Laloki and Brown Rivers, N. G.
609 Korlte River, Menyamya
Bothriochloa decipiens C. E. Hubb
507 Ayr, Queensland
518 Ingham, Queensland
538 Laloki River, N. G.
541 Brown River, N. G.
751 Sentani, Netherlands N. G.
Bothriochloa intermedia (R. Br.) A. Camus
506 Ayr, Queensland
513 Ingham, Queensland
535 Port Moresby, N. G.
560 Lae
752 Sentani, Netherlands N. G.
772 Sorong
821 Honiara, Guadalcanal
Dicanthium sericeum (R. Br.) A. Camus
527 Port Moresby, N. G.
544 Ten miles from Port Moresby on Rouna Falls road
547 Rouna Falls
824 About 16 miles west of Honiara, Guadalcanal
Cymbopogon procerus (R. Br.) Domin
534 Port Moresby
Cymbopogon flexuosus (Noes ex Stend.) Stapf
704 Wewak, N. G.
764 Manokwari, Netherlands N. G.
Hyparrhenia hirta (L.) Stapf
718 Nondugl
Themeda frondosa (R. Br.) Merr
789 Hollandia
810 Madang
Themeda triandra Forsk
635 Gusap
Themeda gigantea (Cav.) Hack.
579 Bubu River, Garaina
604 Korlte River, Menyamya
698 Lumi
Germainia capitata Bal. and Poitr.
691 Green River
Heteropogon contortus (L.) Beauv.
505 Proserpine Airfield, Queensland
Polytoca macrophylla Benth
548 Rouna Falls
561 Lae
597 Wantoat
600 Pine Tops, Bulolo

Polytoca macrophylla Benth — continued

630	Murnass River, near Madang
660	Maprik (small very pubescent form)
804	Maprik (small very pubescent form)
727	Baiyer River
753	Sentani, Hollandia
762	Manokwari
788	Jatufe Bay, 25 miles from Hollandia
799	Ramu River at Aiome
817	Rabaul, New Britain Is.
838	Honiara, Guadalcanal

Coix lacryma-jobi L.

580	Bubu River, Garaina
643	Wewak
675	Telefomin
722	Nondugl
732	Tari
778	Enarotali

Coix lacryma-jobi var. stenocarpa (Oliver) Stapf

676	Telefomin

Coix gigantea Roxb.

805	Sepik River at Pagwi
811	Sepik River at Angoram

Coix gigantea was found to be common on the bank of the Sepik River at Angoram and Pagwi, and many patches were seen in shallow water of the Sepik River between Pagwi and Ambunti. This form has a red tint to the leaves where exposed to the sun, which does not occur in a cultivated form known as Salt Grass which was observed at Mumeng, Wantoat and Tari. At Tari, it is fairly abundant in a swamp "Haibuga" and is not known to flower at this elevation of 5200 feet.

NOTE: Identifications are by the junior author based on fragments from the collections of seed. Regular herbarium specimens were not prepared and seeds of very common species such as *Themeda triandra* Forsk., *Apluda mutica* L. and *Chrysopogon aciculatus* (Retz.) Trin. were not collected generally. Genera such as *Miscanthus*, *Eulalia*, *Microstegium*, *Sorghum* and the rarer species were collected whenever ripe seed was found.

ED FROM BY VARIOUS
TO NEW GUINEA
B 1928
X 1937
o 1951
• 1957
148°
149°
150°
151°
152°
153°
0°
1°
2°
3°
4°
5°
6°
7°
8°
9°
10°
11°
LANDS
NEW HANOVER I.
Kavieng
NEW IRELAND
Rabaul
NEW BRITAIN
HUON GULF
SOLOMON SEA
Popondetta
Rigo
Milne Bay
CORAL SEA

THE USE OF LIGHT TRAPS FOR THE EARLY DETECTION OF NEWLY ESTABLISHED IMMIGRANT INSECT PESTS IN HAWAII

J. W. BEARDSLEY*

Hawaii, by virtue of its location near the center of the Pacific Ocean, has long been the most important "stepping-stone" between the American continents and the Oriental and Australasian regions. Since the advent of transport by aircraft the Islands are now no more than a few hours away from many places on the periphery of the Pacific. With modern methods of transportation, war and military occupation, and the development of the tourist industry in the Islands, has come a great increase in the volume of traffic passing through the airports and harbors of greater Honolulu. This increasing flow of visitors and transients has been attended, largely by accident, by an increasing number of insects and other pests from these distant lands.

Before the arrival of man, the isolation of the Hawaiian Islands allowed the development of a peculiar and specialized native flora and fauna. With the clearing of the land for modern agriculture, most of the native plant-feeding insects disappeared or became restricted with their host plants to the remaining forest regions. Only a very few have been able to adapt themselves to cultivated plants. The sugar cane leafroller, *Omiodes accepta* (Butler), is the only Hawaiian cane insect of consequence which is native to the Islands. All others, including those which in past years caused the most serious losses, have come to us from other parts of the world. The equable climate of the Islands and the absence or ineffectiveness of native parasites and predators enabled foreign pests, once established, to develop destructively high populations in relatively short periods of time. The outbreaks of the sugar cane leafhopper which plagued the industry here in the early years of this century are a case in point. Only the introduction and establishment of parasites and predators from the areas where this pest originated served to reduce its numbers to the point where it is no longer of serious concern.

Were it not for the effective enforcement of plant and animal quarantines by the Federal and Territorial governments, the number of foreign pests which have become established in Hawaii would be far greater than it is. However, it is unlikely that quarantines will ever be made one hundred per cent effective no matter how strictly they are enforced. Records kept by the Hawaiian Entomological Society show that about a dozen or so accidentally imported insects become established in the Islands every year, and that the rate has increased appreciably since the advent of airplane transportation. Not all these insects are harmful, but the list includes a number of pests or potential pests.

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Figure 1. Bermuda grass armyworm moth, Spodoptera mauritia (Boisduval). First discovered in Hawaii in HSPA light trap catch in December 1953.

The sugar industry of Hawaii has been extremely fortunate in that no serious insect pest of the cane plant has become established here in nearly fifty years. Nevertheless, in the various cane growing regions in and around the Pacific there are a number of insects, any one of which might prove highly destructive in Hawaiian fields if established here. Moth borers of the genus *Diatraea* which occur from the southern United States through Central and South America, as well as those belonging to such genera as *Chilotraea*, *Chilo*, *Proceras* and others, in the Philippines and other southwest Pacific areas, are among the potentially serious pests. Root-feeding scarab grubs, such as various species of *Anomala*, as well as many kinds of leafhoppers and leaf-feeding caterpillars, are known to occur in these regions. It is because of the threat posed by these pests that entomologists of the Experiment Station continue to give close scrutiny to all newly arrived immigrant insects.

The earlier the presence of a newly established insect pest can be detected the better, insofar as the initiation of effective control measures is concerned. If detected soon enough, it might be possible to eradicate a serious cane pest before it could gain a strong foothold here. Should eradication prove impractical or impossible, early detection would still permit the initiation of quarantines in time to prevent or delay the spread of the pest to islands outside of Oahu, as has been done in the case of the Anomala beetle. Early detection would also facilitate the rapid implementation of measures designed to limit the damage caused by such a pest, as it would enable plantations and Station entomologists to get an early start on control programs, possibly before damage in the fields had become acute. Should a serious cane pest become established here, the more quickly the search for effective natural enemies which could be introduced into Hawaii for its biological control is begun, the more likely it is that such control can be effected before widespread and serious damage develops, necessitating expensive chemical or cultural control measures.

Figure 2. Tobacco budworm moth, **Heliothis virescens** (Fabricius), a serious pest of tobacco and cotton in the U. S. First found in Hawaii in HSPA light trap catch in April 1956.

Electric light traps provide one of the most effective methods yet devised for the early detection of newly established pest species. H.S.P.A. entomologists have been using light traps, located at strategic spots on Oahu, for this purpose since 1944. During the period over which these have been in operation, thirteen pest or potential pest species have been found for the first time in the Islands in the catches of these traps. These insects, the dates of their first appearance, and their probable origins, are listed in Table I. Some of these insects are illustrated in Figures 1 to 4.

The location of light traps used for the detection of newly immigrant insect pests is an important consideration. Ideally, such traps should be located in plantation areas as near as possible to probable sites of introduction, such as airfields and harbors. Since it is impractical to maintain enough traps to cover all such

TABLE 1. POTENTIAL PEST INSECTS FIRST FOUND IN HAWAII IN HSPA LIGHT TRAPS

Species	Type of Insect	Date First Appeared	Probable Origin
1. *Anacamptodes fragilaria* (Grossbeck)	moth	August, 1944	California
2. *Amyna natalis* (Walker)	moth	Feb., 1945	Southwest Pacific
3. *Elaphria nucicolora* (Guenee)	moth	June, 1945	Southern U.S., Central or South America
4. *Lygus elisus* Van Duzee	plant bug	July, 1947	California
5. *Trichoclea postica* Smith	moth	Sept., 1947	California
6. *Exitianus exitiosus* Uhler	leafhopper	Oct., 1947	Western U.S.
7. *Deltocephalus sonorus* Ball	leafhopper	July, 1952	Southwestern U.S.
8. *Spodoptera mauritia* (Boisduval)	armyworm moth	Dec., 1953	Guam, Philippine Is., or Southwest Pacific
9. *Kunziana kunzei* (Gillette)	leafhopper	Dec., 1954	Southwestern U.S.
10. *Heliothis virescens* (Fabricius)	budworm moth	April, 1956	North America
11. *Meliana* sp.	moth	Sept., 1956	Fiji or Australia
12. *Achaeta domesticus* (L.)	field cricket	Oct., 1956	North America
13. *Phaneroptera furcifera* Stal	katydid	June, 1957	Guam or Philippine Is.

Figure 3. Field and house cricket, **Achaeta domesticus** (L.) Found established in Hawaii in October 1956 from specimens taken in HSPA light traps.

Figure 4. A katydid, **Phaneroptera furcifera** Stal, which is a pest of legumes in the Philippine Islands. First taken in Hawaii in the HSPA light trap at Waipio, Oahu, in June 1957.

locations in the Islands, or even on Oahu where practically all incoming traffic arrives, our traps have been located at what are considered spots of maximum risk. At present, we have two such traps in operation, both situated on the periphery of Pearl Harbor, Oahu, where there is a concentration of port and airfield facilities in close proximity to plantation areas. One trap is located on the grounds of the Experiment Station's Waipio Substation, and the other at Ewa near the Barber's Point Naval Air Station. Through the cooperation of the Staff of the Waipio Substation and the Ewa Plantation Company, the catch from each of these traps is removed every morning and the accumulated material is forwarded to the Entomology Department at the Experiment Station once each week. The accumulated catch is examined weekly by the Station entomologists and any new or unusual insects are removed for identification.

When a new insect appears in the traps, it is often possible to identify it immediately through recourse to the large reference collection of insects housed at

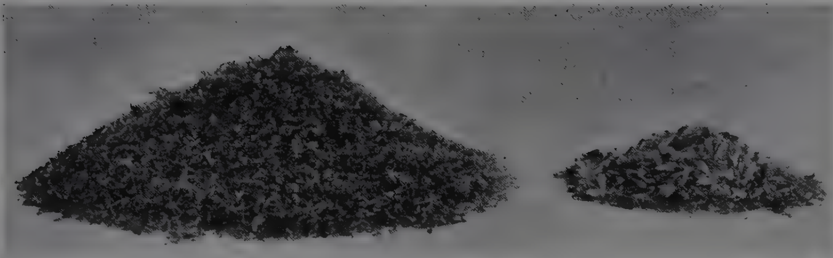

Figure 5. Catch from an ultraviolet trap (left), and a white light trap (right). The piles represent the catch after the traps were operated in the same area for 16 days. The ultraviolet trap catch contains approximately 40,000 insects; the white light trap catch about 7,000.

Figure 6. HSPA light trap at Ewa, Oahu. This trap utilizes a 100-watt mercury vapor type ultraviolet lamp.

Figure 7. HSPA light trap at Waipio Substation, Oahu. This trap is equipped with 15-watt ultraviolet fluorescent tube.

the Experiment Station. In some cases, identification is secured only after specimens have been sent to one of the larger museums, such as the U. S. National Museum in Washington, D. C., or to the British Museum in London. Since the known cane pests are well represented in our collections, it is probable that any of these which arrived here would be recognized as soon as it began to appear in the light trap catches.

The light traps now in operation at Ewa and Waipio utilize ultra-violet sources of radiant energy, the so-called "black light". It has been found that nearly all insects attracted by light are more strongly affected by the ultraviolet wavelengths, in a band just beyond those visible to humans, than by those of the visible portion of the spectrum. Experiments conducted at Waipio to test the relative attractiveness of ultra-violet and conventional light sources showed that the average total catch of the ultra-violet trap was three or more times as great as that of a conventional white-light trap of the same wattage (Figure 5). Those families of insects which contain the potentially most serious pest species, such as the pyralidoid moths and the sugar cane leafhoppers, were all more strongly attracted by ultra-violet light. From these tests it was concluded that any new insect pest of sugar cane gaining entrance to Hawaii would be attracted as well, or better, by traps utilizing ultra-violet light sources as by those using ordinary incandescent bulbs of comparable wattage.

The two traps now in operation in the Pearl Harbor area are each equipped with a different type of ultra-violet light source. The Ewa trap (Figure 6.) utilizes a 240 volt, 100 watt, General Electric H-100, BL4 mercury vapor type lamp. A special transformer, housed beneath the conical roof, is necessary to step up the line-voltage to the required 240 volts. This trap is more suitable for temporary or field installations than is the Waipio trap, as the short gap between the roof and the funnel prevents rainwater from entering and fouling the killing jar and catch. The Waipio trap (Figure 7.) is equipped with a General Electric 110 volt, 15 watt BLB fluorescent tube. This trap proved to be more attractive to most insects than the mercury vapor lamp trap, when the two were compared in tests at Waipio. It also consumes considerably less power and does not require the heavy, expensive transformer necessary for the Ewa trap. The principal disadvantage of the fluorescent tube trap is the relatively long gap between the roof and the funnel which is necessitated by the length of the tube. Before it was permanently installed beneath the extended eaves of one of the Waipio buildings, the killing jars and catches of this trap were frequently ruined by rainwater. The Waipio trap utilizes three plexiglass baffles, installed at 120 degree intervals around the tube, which serve to deflect flying insects, causing them to fall into the funnel and killing jar.

Even ultra-violet light traps have their limitations and they cannot be expected to attract every newly arrived insect immigrant. Certain species of insects, particularly flightless species and some of the day-flying forms, are seldom, if ever, attracted to light. Fortunately, the majority of the potentially serious cane pests which we might expect are nocturnally active. It is also probable that a day-flying pest species is more apt to be spotted by personnel working in the fields and called to the attention of entomologists.

TOTAL PHOSPHORUS IN INTERNODES 8-10 AS A GUIDE TO THE PHOSPHORUS FERTILIZATION OF SUGAR CANE

CONSTANCE E. HARTT*

INTRODUCTION

Phosphorus, an element essential for growth, tillering, and sugar formation in the sugar-cane plant, is applied by the Hawaiian sugar plantations in amounts costing approximately two million dollars per year (8). Current methods of determining proper amounts of fertilizers to apply include both soil and plant analyses. The distribution of phosphorus in field-grown plants was studied statistically (6) and the stem was found to be the most reliable indicator tissue. Either internodes 8–10 or basal internodes were found to give a reliable answer, but since the internodes 8–10 are easier to obtain in the field, they were used in a study of 23 replicated field experiments on 10 plantations on two islands. The results were tabulated in a Special Release (7), together with soil phosphorus, yield response, and other pertinent data. Yield response in tons sugar per acre was that obtained from the previous crop of the experiment. The results pointed to 0.031 per cent phosphorus on the dry weight basis as the tentative critical level for phosphorus in internodes 8–10, at and below which level the application of phosphorus fertilizer was associated with a significant gain in tons sugar per acre.

Final yield data for all the experiments not lost or discontinued have now been obtained. This paper reports the detailed analyses of phosphorus in the plants of all the experiments tabulated in the Special Release, together with the yield data for the previous and current crops, and the soil phosphorus data. The effects of several factors upon the percentage of phosphorus in internodes 8–10 are reported. Four criteria for the purpose of determining critical ranges for phosphorus in the plant are discussed. It is our hope that these figures for levels of phosphorus in internodes 8–10 may help in determining phosphorus applications in the field.

METHODS

Samples were taken early in the morning. Five stalks** were removed from each plot, the leaves stripped off, and stalk portions including joints 8–10 (counting the spindle as #1) were labeled, tied together, placed in bags or boxes, and flown to Honolulu. Slices, cut by a meat slicer from the center of internodes 8, 9 and 10, were caught on clean wax paper or aluminum trays, placed in aluminum cans, dried at 80° C., milled in a Wiley mill, and used for the analysis of total P. Weighed aliquots of 35 milligrams were placed in Pyrex test tubes (marked at 10

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** For a field survey with no replicates, nine stalks from one plot would measure a 30 per cent difference (6).

cubic centimeters), hydrolyzed with 10 N sulphuric acid (0.4 cc) with a little nitric acid (10 drops), for one hour at 150° C. (using an oil bath), oxidized with two to four drops of hydrogen peroxide for 20 minutes at the same temperature, followed by five drops of water to remove residual peroxide, and hydrolyzed with 1 cc of water for 10 minutes in a boiling water bath. At this stage, samples should be clear and colorless liquids. After cooling to room temperature, 0.8 cc of ammonium molybdate solution was added to each tube, followed by 0.4 cc of Fiske reagent. The tubes were made to mark with distilled water, mixed by inverting, allowed to stand 30 minutes for color development; then the phosphorus was determined, using a photo-electric colorimeter with suitable blanks and standards. Results are expressed as percentage of the dry weight.

The reagents were prepared as follows:

Ammonium molybdate solution, 2.5%: Dissolve 12.5 gms. in about 200 cc distilled water, heat to 60° C. and filter. Make to one liter. Keep in a dark bottle.

Fiske reagent: Add 250 mgs. Na 1-amino-2-naphthol-4-sulfonate (Eastman) to 97.5 cc of 15 per cent Na bisulfite (freshly prepared) and 2.5 cc of 20 per cent Na sulfite. Warm in water bath to 40° to 50° C. and stir rapidly until completely dissolved. Keep in a dark bottle.

RESULTS

I. Phosphorus Analyses and Yield Data from Previous and Current Crops.

The experiments are presented by plantation, 19 experiments from the island of Hawaii and four experiments from the island of Kauai (Tables 1–19).

TABLE 1. HAKALAU PLANTATION CO.

Expt. 118 AP × Ca. Variety 44-3098

Yield Data

Plant Crop, 1953 — Age: 26.5 months — 18 replicates

Plot Identity	*lbs. P_2O_5*	*TCA*	*Q.R.*	*Y%C*	*TSA*
A	0	87.7	8.8	11.4	10.0
B	200	90.2	8.7	11.5	10.4
	LSD	ns	—	ns	ns

1st Ratoon Crop, 1955 — Age: 25.5 months — 18 Replicates

Plot Identity	*lbs. P_2O_5*	*TCA*	*P.R.*	*P%C*	*TPA*
A	0	91.5	7.9	12.7	11.6
B	200	92.2	8.1	12.4	11.5
	LSD	ns	—	ns	ns

Phosphorus Data

1st Ratoon Crop, 1955 — 18 replicates

Plot Identity	*lbs. P_2O_5*	*Soil P*		*8–10 P*		
		ppm	*lbs./ac.ft.*	*%*	*Month*	*Age*
A	0	22	33	.050	June	11 mos. 3 wks.
B	200	—	—	.070	June	11 mos. 3 wks.
			LSD	.006		

Comments

1. 200 lbs. P_2O_5 increased 8–10 P by 40%.
2. No significant gains in yield with internode 8–10 P of check plot equalling .050%.
3. Therefore, in this test a phosphorus percentage of .050 in internodes 8–10 indicated there was no need for applications of phosphate.

TABLE 2. HAKALAU PLANTATION CO.

Expt. 119(a) A × FP(res.). Variety 44-3098

Yield Data

Plant Crop, 1953 — Age: 23 months

Plot Identity	*No. of Plots*	*lbs. P_2O_5*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	4	0	83.3	8.5	11.7	9.7
1	6	200	97.9	8.8	11.4	11.1
2	6	400	102.7	9.1	11.0	11.3
LSD (4 vs 6)			12.8			
(6 vs 6)			11.4	—	ns	ns

Phosphorus Data

1st Ratoon Crop, 1955

Plot Identity	*lbs. P_2O_5* res. Cur.	*Soil P* ppm	*Soil P* lbs./ac.ft.	*8–10 P* %	*8–10 P* Month	*8–10 P* Age
X	0+ 0	19	29	.045	June	12 mos. 2 wks.
1	200+200	—	—	.072	June	12 mos. 2 wks.
2	400+ 0	—	—	.060	June	12 mos. 2 wks.
LSD (4 vs 6)				.016		
(6 vs 6)				.014		

Comments

1. 200 lbs. residual plus 200 lbs. current P_2O_5 increased 8–10 by 60%.
2. No significant gain in TSA with internode 8–10 P of check plot equalling .045%.
3. Therefore, in this test a phosphorus percentage of .045 in internodes 8–10 indicated no need for applications of phosphate.

TABLE 3. HAKALAU PLANTATION CO.

Expt. 124 A × FP. Variety 44-3098

Yield Data

Plant Crop, 1954 — Age: 27.3 months

Plot Identity	*No. of Plots*	*lbs. P_2O_5*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	3	0	102.8	9.3	10.7	11.0
A+B	6	200	105.9	9.3	10.7	11.3
C+D	6	400	107.8	9.3	10.8	11.7
		LSD	ns	—	ns	ns

Phosphorus Data

1st Ratoon Crop, 1956

Plot Identity	*lbs. P_2O_5* res. Cur.	*Soil P* ppm	*Soil P* lbs./ac.ft.	*8–10 P* %	*8–10 P* Month	*8–10 P* Age
X	0+ 0	11	17	.059	March	6 mos. 3 wks.
A+B	200+200	—	—	.113	March	6 mos. 3 wks.
C+D	400+ 0	—	—	.087	March	6 mos. 3 wks.
LSD (3 vs 6)				.027		
(6 vs 6)				.022		

Comments

1. 200 lbs. residual plus 200 lbs. current P_2O_5 increased 8–10 P by 91.5%. 400 lbs. residual increased 8–10 P by 47.4%.
2. No significant gains in yield with internode 8–10 P of check plot equalling .059%.
3. Therefore, in this test a phosphorus percentage of .059 indicated no need for application of phosphate.

TABLE 4. HILO SUGAR PLANTATION CO.

Expt. 163(a) A × FP. Variety 44-3098

Yield Data

Plant Crop, 1956 — Age: 23.4 months

Plot Identity	*No. of Plots*	*lbs.* P_2O_5	*TCA*	*P.R.*	*P%C*	*TPA*
X	3	0	98.7	8.3	12.0	11.8
A+B	6	419	108.2	8.9	11.2	12.1
		LSD	ns	—	ns	ns

Phosphorus Data

Plant Crop, 1956

Plot Identity	*lbs.* P_2O_5	8-10 P *%*	8-10 P *Month*	8-10 P *Age*
X	0	.021	March	11 mos. 3 wks.
A+B	419	.026	March	11 mos. 3 wks.
	LSD	ns		

Comments

1. Fertilization with 419 lbs. P_2O_5 gave no significant gain in 8-10 P and no significant gain in TPA.
2. This experiment was exceptional in that a very low percentage of 8-10 P was not associated with a significant gain in yield of sugar. The yield expected from this field was 9.5 TSA (8). Apparently this yield was obtained even though all but two plots contained .022% P or less.

TABLE 5. LAUPAHOEHOE SUGAR CO.

Expt. 36 A × FP. Variety 38-2915

Yield Data

Plant Crop, 1954 — Age: 24.5 months

Plot Identity	*No. of Plots*	*lbs.* P_2O_5	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	3	0	81.7	8.8	11.3	9.1
A+B	6	200	88.8	8.4	11.9	10.6
C+D	6	400	92.2	8.3	12.0	11.0
		LSD (3 vs 6)	ns	—	ns	1.4
		(6 vs 6)	ns	—	ns	1.1

1st Ratoon Crop, 1956 — Age: 24.25 months

Plot Identity	*No. of Plots*	*lbs.* P_2O_5 *res.* + *Cur.*	*TCA*	*P.R.*	*P%C*	*TPA*
X	3	0+ 0	58.3	6.7	14.9	8.7
A+B	6	200+200	72.9	7.0	14.3	10.4
C+D	6	400+ 0	72.8	6.8	14.6	10.6
		LSD (3 vs 6)	7.7	—	ns	.9
		(6 vs 6)	6.2	—	ns	.8

Phosphorus Data

1st Ratoon Crop, 1956

Plot Identity	*lbs.* P_2O_5 *res.* + *Cur.*	Soil P *ppm*	Soil P *lbs./ac.ft.*	8-10 P *%*	8-10 P *Month*	8-10 P *Age*
X	0+ 0	12	22	.027	March	9 mos. 2 wks.
A+B	200+200	—	—	.048	March	9 mos. 2 wks.
C+D	400+ 0	—	—	.041	March	9 mos. 2 wks.
	LSD (3 vs 6)			.007		
	(6 vs 6)			.005		

Comments

1. 200 lbs. residual plus 200 lbs. current P_2O_5 increased 8-10 P by 77.8%. 400 lbs. residual with no current P_2O_5 increased 8-10 P by 51.8%.
2. Significant gains in yield with internode 8-10 P of check plot equalling .027%.
3. Therefore, in this test a phosphorus percentage of .027 in internodes 8-10 indicated a need for fertilization with phosphate.

TABLE 6. KOHALA SUGAR COMPANY

Phosphorus Data

Exp. No.	Field	Variety	Crop	Age at Sampling	Soil P ppm	Soil P lbs./ac.ft.	8–10 P O	8–10 P 500 RR	8–10 P 500 SP	8–10 P 500 AP	CV. %	LSD
198(a)	Upolo 12	44-3098	Plant, 1955	12 mos. 1 wk.	105	305	.110	.112	.098	.135	17.5	.024
198(b)	Upolo 12	38-2915	Plant, 1955	12 mos.	21	61	.037	.057	.053	.045	33.3	.019
198(c)	Puakea 10	38-2915	Plant, 1955	11 mos. 2 wks.	54	155	.065	.091	.075	.062	26.0	ns
198(d)	Puakea 10	38-2915	Plant, 1955	11 mos. 1 wk.	94	275	.125	.088	.131	.091	17.4	ns
							O	150 SP		300 SP		
199	Alaalae 8	38-2915	Plant, 1955	9 mos. 3 wks.	63	185	.117	.115		.100	25.2	ns

Comments

1. No yield data.
2. No visible differences.

TABLE 7. OLAA SUGAR CO.

Expt. 101(a and b) AP Ca × ANK. Variety 44–3098

Yield Data

Plant Crop, 1953 — Age: 24 months

Plot Identity	*No. of Plots*	*lbs. P_2O_5*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	8	0	59.9	7.4	13.6	8.2
A+B+C	24	200	75.4	7.6	13.2	9.9
		LSD	10.5	—	ns	1.3

1st Ratoon Crop, 1955 — Age: 27 months — 8 replicates

Plot Identity	*Treatment lbs. P_2O_5*	*Treatment lbs. CaO*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	0	0	71.8	8.4	11.9	8.6
A	200	0	81.9	8.4	11.9	9.8
B	200	290	91.0	8.2	12.2	11.1
C	200	580	95.3	8.5	11.8	11.3
		LSD	4.0	—	ns	.7

Phosphorus Data

1st Ratoon Crop, 1955

Plot Identity	*No. of Plots*	*lbs. P_2O_5*	*Soil P ppm*	*Soil P lbs./ac.ft.*	*8–10 P %*	*8–10 P Month*	*8–10 P Age*
X	5	0	28	26	.029	February	6 mos.
A	5	200	—	—	.053	February	6 mos.
		LSD			.008		
X	8	0	28	26	.031	June	10 mos. 2 wks.
A+B+C	24	200	—	—	.046	June	10 mos. 2 wks.
		LSD			.009		
X	8	0	28	26	.026	July	11 mos. 2 wks.
A+B+C	24	200	—	—	.038	July	11 mos. 2 wks.
		LSD			.007		

Comments

1. 200 lbs. P_2O_5 significantly increased the 8–10 P. When sampled in February the gain was 82.7%; in June, 48.4%; and in July, 46.1%
2. Significant gains in TSA in both plant crop and 1st ratoon crop, with internode 8–10 P of check plots equalling .026–.031%.
3. Therefore, in this experiment values of .026–.031 for 8–10 P indicated the need for fertilization with phosphate.

TABLE 8. OLAA SUGAR CO.

Expt. 103 AFP(res.). Variety 44–3098

Yield Data

Plant Crop, 1953			Age: 20.3 months			
Plot Identity	*No. of Plots*	*lbs.* P_2O_5	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	8	0	62.4	9.2	10.9	6.8
A+B+C	24	400	72.5	9.1	11.0	7.9
			LSD 5.3	—	ns	.5

1st Ratoon Crop, 1955			Age: 24.5 months			
Plot Identity	*No. of Plots*	*lbs.* P_2O_5 *res. Cur.*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	8	0+ 0	75.5	8.8	11.4	8.6
1	12	400+ 0	92.2	8.8	11.4	10.5
2	12	400+200	91.2	9.0	11.1	10.1
	LSD	(8 vs 12)	6.1	—	ns	.7
		(12 vs 12)	5.4	—	ns	.7

Phosphorus Data

1st Ratoon Crop, 1955							
Plot Identity	*No. of Plots*	*lbs.* P_2O_5	*Soil P*		*8–10 P*		
		res. Cur.	*ppm*	*lbs./ac.ft.*	*%*	*Month*	*Age*
X	8	0+ 0	25	11	.022	June	8 mos. 2 wks.
1	12	400+ 0	—	—	.029	June	8 mos. 2 wks.
2	12	400+200	—	—	.040	June	8 mos. 2 wks.
		LSD			.005		

Comments

1. 400 lbs. residual P_2O_5 increased 8–10 P by 31.8%. With 200 lbs. additional P_2O_5, the gain in 8–10 P was 81.8%.
2. Significant gains in TSA (both crops) with internode 8–10 P of check plot equalling .022%.
3. Therefore, a phosphorus percentage of .022% in internodes 8–10 indicated the need for fertilization with phosphate, in this test.

TABLE 9. OLAA SUGAR CO.

Expt. 105 A × FP. Variety 44–3098

Yield Data

Plant Crop, 1954			Age: 25 months			
Plot Identity	*No. of Plots*	*lbs.* P_2O_5	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	3	0	56.5	7.6	13.1	7.4
A+B	6	200	72.7	7.5	13.4	9.7
			LSD 9.0	—	ns	1.2

Phosphorus Data

1st Ratoon Crop, 1956							
Plot Identity	*No. of Plots*	*lbs.* P_2O_5	*Soil P*		*8–10 P*		
			ppm	*lbs./ac.ft.*	*%*	*Month*	*Age*
X	3	0	30	22	.020	March	8 mos. 3 wks.
A+B	5*	200	—	—	.027*	March	8 mos. 3 wks.
		LSD			.003*		

* With allowance for Plot 6A (with a high %P giving a high C.V.)

Comments

1. 200 lbs. P_2O_5 increased 8–10 P by 35%.
2. Significant gain in TSA in Plant Crop with internode 8–10 P of check plot equalling .020%.
3. Therefore, in this test a phosphorus value of .020% in internodes 8–10 was associated with the need for fertilization with phosphate.

TABLE 10. OLAA SUGAR CO.

Expt. 109(a)res. AP × CaO. Variety 44–3098

Yield Data

Plant Crop, 1954 — Age: 19.5 months — 12 replicates

Plot Identity	*lbs.* P_2O_5	*TCA*	*Q.R.*	*Y%C*	*TSA*
A	0	72.5	7.4	13.5	9.8
B	200	82.6	7.5	13.4	11.1
C	400	84.0	7.4	13.5	11.3
		LSD 4.8	—	ns	.7

1st Ratoon Crop, 1956 — Age: 24 months — 12 replicates

Plot Identity	*lbs.* P_2O_5 *res. Cur.*	*TCA*	*Q.R.*	*Y%C*	*TSA*
A	0+ 0	90.5	8.5	11.7	10.5
B	200+200	94.9	8.9	11.2	10.6
C	400+ 0	93.6	8.8	11.4	10.7
		LSD 3.2	—	ns	ns

Phosphorus Data

1st Ratoon Crop, 1956 — 12 replicates

Plot Identity	*lbs.* P_2O_5		*Soil P*			*8–10 P*		
	res.	*Cur.*	*ppm*	*lbs./ac.ft.*		*%*	*Month*	*Age*
A	0+	0	16,20, 41	15,23,48 (=29 Av.)		.030	February	8 mos. 3 wks.
B	200+	200	—	—		.044	February	8 mos. 3 wks.
C	400+	0	—	—		.039	February	8 mos. 3 wks.
					LSD	.004		
A						.034	May–June	12 mos.
B						.041	May–June	12 mos.
C						.038	May–June	12 mos.

Comments

1. 200 lbs. residual plus 200 lbs. current P_2O_5 increased 8–10 P by 46.7%. 400 lbs. residual with no current P_2O_5 increased 8–10 P by 30%.
2. Significant gains in TSA in plant crop but not in ratoon crop, with internode 8–10 P of check plot equalling .030–.034%.
3. Since the previous crop responded significantly in TSA but the current crop did not, phosphorus percentages of .030–.034 in the zero phosphate plots may be considered to be borderline.

TABLE 11. ONOMEA SUGAR CO.

Expt. 71 A × FP. Variety 44-3098

Yield Data

Plant Crop, 1954		Age: 28 months				
Plot Identity	*No. of Plots*	*lbs. P_2O_5*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	3	0	91.3	9.9	10.1	9.1
A+B	6	200	106.7	10.0	10.0	10.7
C+D	6	400	104.5	9.7	10.3	10.8
			LSD ns	—	ns	ns

1st Ratoon Crop, 1956		Age: 25.9 months				
Plot Identity	*No. of Plots*	*lbs. P_2O_5* *res. Cur.*	*TCA*	*P.R.*	*P%C*	*TPA*
X	3	0+ 0	96.0	8.7	11.5	10.8
A+B	6	200+200	101.6	9.1	11.0	11.2
C+D	6	400+ 0	106.2	8.6	11.6	12.3
	LSD	(3 vs 6)	ns	—	ns	1.3
		(6 vs 6)	ns	—	ns	1.0

Phosphorus Data

1st Ratoon Crop, 1956		*lbs. P_2O_5*	*Soil P*		*8–10 P*		
Plot Identity	*No. of Plots*	*res. Cur.*	*ppm*	*lbs./ac.ft.*	*%*	*Month*	*Age*
X	3	0+ 0	10	15	.039	March	6 mos.
A+B	6	200+200	—	—	.072	March	6 mos.
C+D	6	400+ 0	—	—	.076	March	6 mos.
			LSD	(3 vs 6)	.015		
				(6 vs 6)	.012		

Comments

1. 200 lbs. residual plus 200 lbs. current P_2O_5 increased 8–10 P by 84.6%. 400 lbs. residual with no current P_2O_5 increased 8–10 P by 94.9%.
2. No significant gains in yield in plant crop, but in 1st ratoon crop a significant gain in TPA in plots C+D (400 lbs. residual P_2O_5). 8–10 P of check plot equalled .039%.
3. Since only one out of four gains in yield was significant, the value .039 for 8–10 P may be borderline.

TABLE 12. PAAUHAU SUGAR PLANTATION CO.

Expt. 107(a) AP × K. Variety 38–2915

Yield Data

Plant Crop, 1953 — Age: 25.5 months — 6 replicates

1st Ratoon Crop, 1955 — Age: 23.5 months — 6 replicates

Plot Identity	*lbs. P_2O_5*	*TCA* Plant	*TCA* Rat.	*Q.R.* Plant	*Q.R.* Rat.	*Y%C* Plant	*Y%C* Rat.	*TSA* Plant	*TSA* Rat.
A	0	68.6	58.4	9.3	8.3	10.7	12.1	7.3	7.1
B	200	71.1	60.9	9.3	8.5	10.8	11.8	7.6	7.2
C	400	73.1	58.6	9.5	8.2	10.5	12.2	7.7	7.1
	LSD	ns	ns	—	—	ns	ns	ns	ns

Phosphorus Data

1st Ratoon Crop, 1955 — 6 replicates

Plot Identity	*lbs. P_2O_5* res.	Cur.	*Soil P* ppm	*Soil P* lbs./ac.ft.	*8–10 P* %	*8–10 P* Month	*8–10 P* Age
A	0+	0	44	79	.049	August	12 mos. 2 wks.
B	200+	0	—	—	.044	August	12 mos. 2 wks.
C	400+	0	—	—	.053	August	12 mos. 2 wks.
				LSD	ns		

Comments

1. Residual P_2O_5 made no significant difference in 8–10 P.
2. No significant gains in yield with internode 8–10 P of check plot equalling .049%.
3. Therefore, the value of .049 was indicative of no need for phosphate fertilization under these conditions.

TABLE 13. PAAUHAU SUGAR PLANTATION CO.

Expt. 107(b) AP × K. Variety 38–2915

Yield Data

Plant Crop, 1954 — Age: 24.5 months — 6 replicates

Plot Identity	*lbs. P_2O_5*	*TCA*	*Q.R.*	*Y%C*	*TSA*
A	0	65.6	8.1	12.3	8.1
B	200	71.3	8.1	12.4	8.8
C	400	74.0	8.3	12.1	9.0
	LSD	5.6	—	ns	0.5

1st Ratoon Crop, 1956 — Age: 24.5 months — 6 replicates

Plot Identity	*lbs. P_2O_5* res.	Cur.	*TCA*	*P.R.*	*P%C*	*TPA*
A	0+	0	86.1	6.7	14.9	12.8
B	200+	0	89.4	6.6	15.2	13.6
C	400+	0	90.6	6.7	14.9	13.5
		LSD	ns	—	ns	ns

Phosphorus Data

1st Ratoon Crop, 1956 — 6 replicates

Plot Identity	*lbs. P_2O_5* res.	Cur.	*Soil P* ppm	*Soil P* lbs./ac.ft.	*8–10 P* %	*8–10 P* Month	*8–10 P* Age
A	0+	0	42	76	.031	January	6 mos.
B	200+	0	—	—	.033	January	6 mos.
C	400+	0	—	—	.034	January	6 mos.
				LSD	ns		

Comments

1. Residual phosphate made no significant difference in 8–10 P.
2. Significant gains in yield in plant crop, but not in ratoon crop, with internode 8–10 P of check plot equalling .031%.
3. Therefore, a phosphorus percentage of .031 in internodes 8–10 of zero phosphate plots may be considered a borderline value in this experiment.

TABLE 14. PEPEEKEO SUGAR CO.
Expt. 82 A × FP. Variety 44–3098

Yield Data

Plant Crop, 1953 — Age: 23.6 months

Plot Identity	*No. of Plots*	*lbs. P_2O_5*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	10	0	81.3	8.7	11.5	9.3
1	15	200	90.3	8.8	11.4	10.2
2	15	400	100.4	8.8	11.4	11.4
	LSD	(15 vs 15)	7.8	—	ns	.9
		(10 vs 15)	9.6	—	ns	1.1

1st Ratoon Crop, 1954 — Age: 20.4 months

Plot Identity	*No. of Plots*	*lbs. P_2O_5* res. Cur.	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	10	0+ 0	104.1	9.1	11.0	11.4
1	15	200+200	108.9	9.3	10.8	11.7
2	15	400+ 0	105.9	9.3	10.8	11.4
		LSD	ns	—	ns	ns

Phosphorus Data

1st Ratoon Crop, 1954

Plot Identity	*No. of Plots*	*lbs. P_2O_5*		*Soil P*		*8–10 P*		
		res.	*Cur.*	*ppm*	*lbs./ac.ft.*	*%*	*Month*	*Age*
X	10	0+	0	14	21	.022	November	7 mos. 2 wks.
1	15	200+	200	—	—	.037	November	7 mos. 2 wks.
2	15	400+	0	—	—	.032	November	7 mos. 2 wks.
		LSD		(15 vs 15)		.008		
				(10 vs 15)		.009		
X	5	0+	0			.027	December	9 mos. 1 wk.
S1	5	200+	200			.047	December	9 mos. 1 wk.
		LSD				.010		

Comments

1. 200 lbs. residual plus 200 lbs. current P_2O_5 increased 8–10 P by 68%. 400 lbs. residual with no current P_2O_5 increased 8–10 P by 45%.
2. Significant gains in yield in plant crop, but not in ratoon crop due to marked improvement of the zero phosphate plots.
3. This experiment was exceptional in that 8–10 P levels of .022–.027% in the zero phosphate plants were not associated with significant current yield gains in plots receiving P_2O_5. Perhaps this exception was due to season. Both sampling dates were in the season of poor growth.

TABLE 15. PEPEEKEO SUGAR CO.
Expt. 88 A × FP. Variety 44–3098

Yield Data

Plant Crop, 1954 — Age: 23 months

Plot Identity	*No. of Plots*	*lbs. P_2O_5*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	3	0	83.6	9.4	10.6	8.8
A+B	6	200	82.2	9.8	10.2	8.4
C+D	6	400	84.4	9.5	10.5	8.8
		LSD	ns	—	ns	ns

Phosphorus Data

1st Ratoon Crop, 1956

Plot Identity	*No. of Plots*	*lbs. P_2O_5*		*Soil P*		*8–10 P*		
		res.	*Cur.*	*ppm*	*lbs./ac.ft.*	*%*	*Month*	*Age*
X	3	0+	0	18	27	.032	March	11 mos.
A+B	6	200+	200	—	—	.047	March	11 mos.
C+D	6	400+	0	—	—	.034	March	11 mos.
		LSD				ns		

Comments

1. No significant difference in 8–10 P due to high coefficient of variation (30.8%).
2. No significant gains in yield with internode 8–10 P of check plot equalling .032%.
3. Therefore, in this test an 8–10 P value of .032% indicated no need for applications of P_2O_5.

TABLE 16. THE LIHUE PLANTATION COMPANY, LTD.

Expt. 339 AP × K. Variety 38–2915

Yield Data

Plant Crop, 1952		Age: 23.6 months			12 replicates
Plot Identity	*lbs.* P_2O_5	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	0	96.2	11.8	8.5	8.2
Y	100	94.9	11.9	8.4	8.0
Z	194	95.4	12.0	8.3	7.9
	LSD	ns	—	ns	ns

1st Ratoon Crop, 1954		Age: 24.3 months			12 replicates
Plot Identity	*lbs.* P_2O_5 *Plant 1st Ratoon*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	0 + 0	81.8	10.6	9.4	7.7
Y	100 + 100	85.1	10.9	9.2	7.9
Z	194 + 194	79.2	11.1	9.0	7.4
	LSD	ns	—	ns	ns

2nd Ratoon Crop, 1956		Age: 22.7 months			12 replicates
Plot Identity	*lbs.* P_2O_5 *Plant 1st Ratoon 2nd Ratoon*	*TCA*	*P.R.*	*P%C*	*TPA*
X	0 + 0 + 0	95.0	8.5	11.8	11.3
Y	100 + 100 + 250	94.4	8.8	11.4	10.8
Z	194 + 194 + 1000	105.2	9.0	11.1	11.8
	LSD	ns	—	.5	ns

Phosphorus Data

2nd Ratoon Crop, 1956						12 replicates
Plot Identity	*Current* P_2O_5	*Soil P*		*8–10 P*		
		ppm	*lbs./ac.ft.*	*%*	*Month*	*Age*
X	0	12	35	.035	March	10 mos. 2 wks.
Y	250	—	—	.050	March	10 mos. 2 wks.
Z	1000	—	—	.070	March	10 mos. 2 wks.
	LSD			.011		

Comments

1. 250 lbs. P_2O_5 (current) increased 8–10 P by 42.8%. 1000 lbs. P_2O_5 (current) increased 8–10 P by 100%.
2. No significant gains in yield (3 crops) with internode 8–10 P of check plot equalling .035%.
3. Therefore, a value of .035% P in internodes 8–10 indicated no need for fertilization with phosphate in this experiment.

TABLE 17. THE LIHUE PLANTATION COMPANY, LTD.

Expt. 351 AP × K. Variety 44-3098

Yield Data

Plant Crop, 1952 — Age: 20.9 months — 12 replicates

Plot Identity	*lbs.* P_2O_5	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	0	88.5	8.8	11.3	10.0
Y	200	92.4	9.0	11.1	10.3
Z	400	91.9	8.8	11.3	10.3
	LSD	ns	—	ns	ns

1st Ratoon Crop, 1954 — Age: 21.1 months — 12 replicates

Plot Identity	*lbs.* P_2O_5 *Plant*	*1st Ratoon*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	0	+ 0	108.2	10.0	10.0	10.8
Y	200	+ 228	106.2	10.6	9.4	10.0
Z	400	+ 456	103.4	10.5	9.5	9.8
		LSD	ns	—	.4	ns

2nd Ratoon Crop, 1956 — Age: 23.2 months — 12 replicates

Plot Identity	*lbs.* P_2O_5 *Plant*	*1st Ratoon*	*2nd Ratoon*	*TCA*	*P.R.*	*P%C*	*TPA*
X	0	+ 0	+ 0	87.9	10.5	9.52	8.4
Y	200	+ 228	+ 200	83.5	11.1	8.98	7.5
Z	400	+ 456	+ 400	86.6	10.9	9.20	8.0
			LSD	ns	—	.35	ns

Phosphorus Data

2nd Ratoon Crop, 1956 — 12 replicates

Plot Identity	*Current* P_2O_5	*Soil P ppm*	*Soil P lbs./ac.ft.*	*8–10 P %*	*Month*	*Age*
X	0	15	44	.064	December	9 mos. 1 wk.
Y	200	—	—	.090	December	9 mos. 1 wk.
Z	400	—	—	.093	December	9 mos. 1 wk.
			LSD	.018		

Comments

1. 200 lbs. P_2O_5 (current) increased 8–10 P by 40.6%. 400 lbs. P_2O_5 (current) increased 8–10 P by 45.3%.
2. No significant gains in yield (3 crops) with internode 8–10 P of check plot equalling .064%.
3. Therefore, a phosphorus value of .064% indicated no need for fertilization with P_2O_5 in this experiment.

TABLE 18. THE LIHUE PLANTATION COMPANY, LTD.

Expt. 354 AP × K. Variety 37–1933

Yield Data

Plant Crop, 1952 — Age: 17.1 months — 12 replicates

Plot Identity	*lbs. P_2O_5*	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	0	69.6	8.3	12.0	8.3
Y	100	70.8	8.3	12.1	8.6
Z	194	73.4	8.3	12.0	8.8
	LSD	ns	—	ns	ns

1st Ratoon Crop, 1954 — Age: 23.4 months — 12 replicates

Plot Identity	*lbs. P_2O_5* Plant		*lbs. P_2O_5* 1st Ratoon	*TCA*	*Q.R.*	*Y%C*	*TSA*
X	0	+	0	90.0	8.6	11.6	10.5
Y	100	+	100	97.5	8.7	11.5	11.2
Z	194	+	194	97.7	8.6	11.6	11.3
			LSD	4.9	—	ns	.6

2nd Ratoon Crop, 1956 — Age: 21.3 months — 12 replicates

Plot Identity	*lbs. P_2O_5* Plant		*1st Ratoon*		*2nd Ratoon*	*TCA*	*P.R.*	*P%C*	*TPA*
X	0	+	0	+	0	76.7	7.13	14.03	10.76
Y	100	+	100	+	100	86.2	6.95	14.38	12.37
Z	194	+	194	+	200	83.6	7.09	14.11	11.82
					LSD	ns	—	ns	ns

Interactions for TPA (n = 4)

	lbs. P_2O_5	*lbs. K_2O* 0	*250*	*500*
X	0	11.03	11.05	10.20
Y	100	10.69	12.17	14.24
Z	200	9.77	12.40	13.28
				LSD 1.85

Phosphorus Data

2nd Ratoon Crop, 1956 — 12 replicates

Plot Identity	*Current P_2O_5*	*Soil P* ppm	*Soil P* lbs./ac.ft.	*8–10 P* %	*Month*	*Age*
X	0	13	38	.021	March	7 mos. 2 wks.
Y	100	—	—	.025	March	7 mos. 2 wks.
Z	200	—	—	.031	March	7 mos. 2 wks.
			LSD	.003		

Comments

1. Fertilization with phosphate significantly raised the phosphorus level, but only to .025 and .031%. Similar low results were reported by Toyofuku (11) in samples taken May 31 to October 26, 1955: X–.018; Y–.022 and Z–.022%. Toyofuku remarked that both insufficient moisture and low nitrogen supply were limiting factors in the efficient utilization of phosphate.
2. No significant gains in yield in plant crop. Significant gains in TSA in 1st ratoon crop. In 2nd ratoon crop, gains in TPA "were not proven statistically significant due to a high coefficient of variation" (11). However, at the high level of fertilization with potash highly significant gains in TPA were obtained with 100 and 200 lbs. P_2O_5.
3. It is concluded, therefore, that in this experiment a phosphorus level of .021% indicated the need of fertilization with phosphate, but that where potassium or moisture are limiting, the absorption and response to phosphate may not be obtained. Clements (3) reported that in severe potash deficiency, phosphate depresses yield.

TABLE 19. GROVE FARM CO.

Expt. 141AP(=122AP). Variety 44–3098

Yield Data

Plant Crop, 1954 — Age: 19.1 months — 7 replicates

Plot Identity	*lbs. P_2O_5*		*TCA*	*Q.R.*	*Y%C*	*TSA*
X	0		63.3	11.1	9.0	5.7
A	200		66.2	11.0	9.1	6.0
		LSD	ns	—	ns	ns

1st Ratoon Crop, 1956 — Age: 22.3 months — 7 replicates

Plot Identity	*lbs. P_2O_5* res. Cur.		*TCA*	*P.R.*	*P%C*	*TPA*
X	0+ 0		68.9	8.3	12.0	8.3
A	200+200		76.3	8.3	12.1	9.2
		LSD	ns	—	ns	ns

Phosphorus Data

1st Ratoon Crop, 1956 — 7 replicates

Plot Identity	*lbs. P_2O_5*	*Soil P*			*8–10 P*		
	res. Cur.	*ppm*	*lbs./ac.ft.*		*%*	*Month*	*Age*
X	0+ 0	10	29		.040	April	6 mos.
A	200+200	—	—		.089	April	6 mos.
				LSD	.017		

Comments

1. 200 lbs. residual plus 200 lbs. current P_2O_5 increased 8–10 P by 122%.
2. No significant gains in yield with internode 8–10 P of check plot equalling .040%.
3. Therefore, in this test a phosphorus percentage of .040 in internodes 8–10 of zero phosphate plants indicated no need for fertilization with phosphate.

II. Factors Affecting the Percentage of Phosphorus in Internodes 8–10.

Several factors which influence the percentage of phosphorus in internodes 8–10 have been studied and will be discussed in the following order: supply of soluble phosphorus, amounts of K, N, Ca, or Mg available, age of plant, varieties, primary stalks vs suckers, shade vs no shade, and temperature.

Supply of Phosphorus.

The most important factor affecting the percentage of phosphorus in internodes 8–10 is the supply of soluble phosphorus. This will be illustrated by studies with nutrient solutions and field experiments.

In Figure 1, the results of four studies with nutrient solutions are graphed. With 1 ppm P in the solution, the 8–10 P was 0.015, which is very low. With 2 ppm P, the percentage of 8–10 P was 0.030, and continued to increase with increasing supplies of phosphorus. With 34 ppm P, the 8–10 P was 0.210. Results obtained in the field also showed that total P in internodes 8–10 increased with increasing supply of phosphorus.

The relation of soil P to plant P is illustrated by the results from Kohala Sugar Company, Expt. 198(a, b, c, d) AxFP, as shown in Table 20. Plants from the check plots (with no added phosphate) were analyzed. With 21 ppm P in the soil (61 pounds per acre foot), the 8–10 P was 0.037 per cent. With increased P in the soil up to 94 ppm P (275 pounds per acre foot), the 8–10 P increased to 0.125 per cent. But a further increase in soil P did not result in a further increase in 8–10 P.

Table 20 also records the percentages of inorganic and organic P in internodes

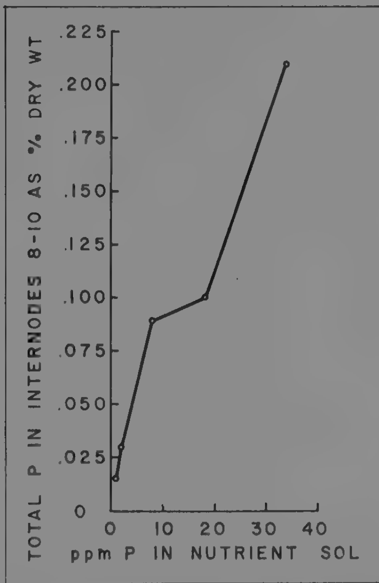

Figure 1. Effect of phosphorus supply in nutrient solution on total P in internodes 8-10. Results of four tests averaged.

8–10. There was a closer relation between inorganic P in the plant and soil P than there was between either total or organic P in the plant and soil P.

Comparing Location d with b, the following ratios are obtained: 4.5 to 1 for soil P; 3.4 to 1 for 8–10 total P; 4.3 to 1 for 8–10 inorganic P; 2.1 to 1 for 8–10 organic P. So, in luxury consumption of phosphate, it is the inorganic form that accumulates more than the organic.

As will be shown in the discussion, in experiments on the island of Hawaii, 83 per cent of variation in plant P was due to variation in soil P (Figure 7, p. 267).

Supply of Potassium, Nitrogen, Calcium and Magnesium.

In a water culture experiment, the supply of potassium, nitrogen, calcium, or magnesium was varied while a uniform supply of phosphorus of approximately 33 ppm P was maintained. Total phosphorus in internodes 8–10 was determined at the age of seven months and three weeks, and the results are presented in Figure 2. Increasing the supply of any of these essential elements resulted in a decreased percentage of total phosphorus in internodes 8–10.

More striking results with nitrogen, obtained from the American Factors Test and published by Burr (2), are reprinted in Figures 3 and 4. Figure 3 shows the

TABLE 20. PHOSPHORUS ANALYSES OF CHECK PLOTS IN LOCATIONS WITH FOUR LEVELS OF SOIL PHOSPHATE

Kohala Sugar Co., Expt. 198 (a, b, c, d) A×FP. P in internodes 8–10 Age: about 1 year

Location	Var.	Soil P		P as % Dry Weight		
		ppm	lbs./ac.ft.	Total	Inorganic	Organic
(b)	2915	21	61	.037	.023	.013
(c)	2915	54	155	.065	.045	.020
(d)	2915	94	275	.125	.099	.027
(a)	3098	105	305	.110	.085	.025

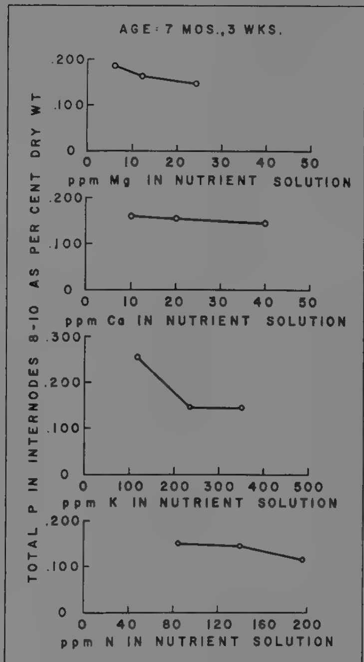

Figure 2. Effects of Mg, Ca, K and N on total P in internodes 8-10.

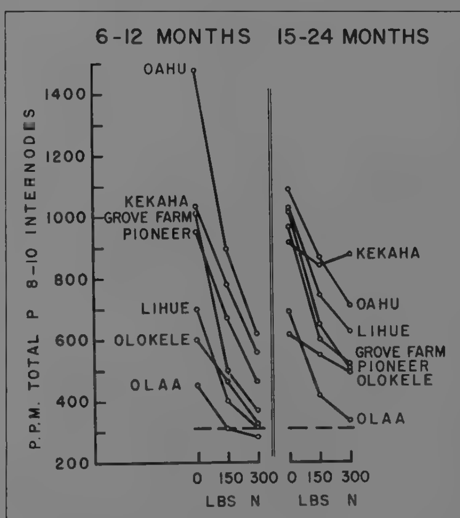

Figure 3. Depression of 8-10 internode P by N applications in the American Factors Test. (After Burr)

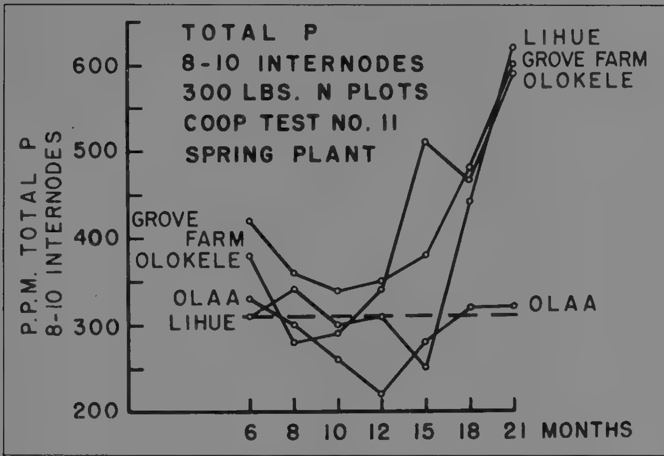

Figure 4. Total P in internodes 8-10 of plants aged 6 to 21 months which had received 300 pounds N. (After Burr)

depression of 8–10 internode P by nitrogen applications. According to Burr, "The effect is extremely uniform, regardless of the absolute level of 8–10 P which depends upon the supply of available soil P. In the first season, while nitrogen is still in excess, the root systems small, and the growth rapid, the 300-pound applications bring levels of P on some of the plantations down to that tentatively set as critical—310 ppm in 8–10 internodes."

Figure 4 shows the effect of 300 pounds N on 8–10 P in plants six to 21 months of age. On some plantations, cane may have been temporarily deficient in phosphorus despite the application with the seed of 200 pounds per acre of P_2O_5.

A depressing effect of nitrogen upon 8–10 P was also obtained in the Physiology and Biochemistry Department's levels-of-N test in field-grown plants at Makiki as shown in Table 21. Soil at Makiki contains more P than at the plantations mentioned in Figure 4, for which reason the P level at Makiki was not depressed to a critical level.

Age.

The effect of age upon 8–10 P is shown in Figure 4. High nitrogen plants at Lihue, Grove Farm and Olokele contained more total P at 21 months of age than

TABLE 21. P & B LEVELS OF N TEST VAR. 37–1933
8–10 P IN FIELD-GROWN PLANTS AT MAKIKI

lbs. N/A	Age in Months							Av.
	6	8	11	13	16	20	23	8–10 P
0	.201	.153	.145	.149	.148	.132	.167	.156
50	.149	.127	.123	.144				.133
75			.121	.130				.125
100	.142	.119	.104	.111	.107	.118	.126	.118
150			.113	.107				.110
200	.111	.105	.098	.099	.113	.122	.103	.107
300			.074	.058				.066
400			.134	.072	.105	.093	.096	.100

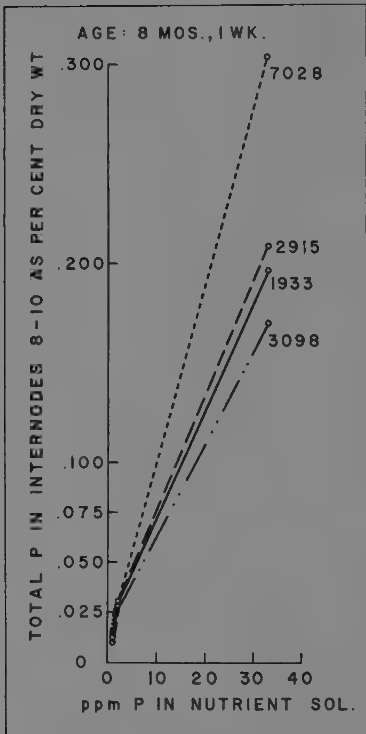

Figure 5. Total P in internodes 8-10 of four varieties grown with three amounts of P.

at any previous age. The phosphorus in plants at Olaa increased from 12 to 21 months, but never regained the original value.

The effect of age of plant upon phosphorus deficiency was discussed by Gilbert (5), who stated that some plants may be deficient in phosphorus in their juvenile stage when their root system is poorly developed, but may show no symptoms when their roots have enlarged and penetrated to deeper soil layers.

Varieties

The percentages of total phosphorus in internodes 8–10 of four varieties grown in water culture at three levels of phosphorus and harvested at the age of eight months and one week were determined. The results are recorded in Table 22 and Figure 5. When the supply of phosphorus in the nutrient solution was high (33

TABLE 22. TOTAL P IN INTERNODES 8–10 OF 4 VARIETIES GROWN WITH 3 AMOUNTS OF P, AS % DRY WEIGHT. AGE: 8 MOS. 1 WK.

Variety	Control (33 ppm P)	2 ppm P	1 ppm P
37-1933	.197	.031	.010
39-7028	.304	.028	.014
44-3098	.170	.027	.011
38-2915	.208	.027	.015

TABLE 23. PRIMARIES VS. SUCKERS
TOTAL P IN INTERNODES 8–10 AS % DRY WEIGHT,
FALL PLANT OF THE AMERICAN FACTORS TEST

Treatment		Oahu Sugar Company		Pioneer Mill Company	
#N	#K	Primary	Sucker	Primary	Sucker
		Age 12 months			
0	0	.114	.059	.104	.103
0	200	.138	.104	.103	.109
0	400	.174	no data	.078	.106
150	0	.091	.122	.021	.033
150	200	.055	.105	.045	.034
150	400	.077	no data	.038	.051
300	0	.108	.100	.037	.035
300	200	.042	.084	.029	.039
300	400	.061	.134	.028	.041
	Avg.	.095	.101	.054	.061
		Age 15 months			
0	0	.093	.130	.075	.070
0	200	.100	.116	.085	.067
0	400	.053	.113	.072	.068
150	0	.074	.130	.027	.023
150	200	.070	.119	.040	.030
150	400	.063	.111	.043	.033
300	0	.061	.107	.030	.043
300	200	.040	.102	.030	.041
300	400	.080	.105	.033	.031
	Avg.	.070	.115	.048	.045

ppm P), the 8–10 P varied considerably in the four varieties. But when the supply was low (1 to 2 ppm P), the 8–10 P was more uniform.

Primary Stalks vs Suckers

Suckers may have the same percentage of total P in internodes 8–10 as primaries, or they may have more or less, as shown in Table 23. Table 23 presents 8–10 P values for primary and sucker stalks from the same plots, these results being taken from two representative harvests of the fall plant of the American Factors Test, from Oahu Sugar and Pioneer Mill. Because of the possibility of differences in 8–10 P found in primaries and suckers, only primary stalks should be taken for diagnostic purposes.

The results presented in Section I of this report were obtained from plants aged approximately six to 12 months and were from primary stalks.

Shade vs No Shade

The general effect of shade is to increase the 8–10 P. This result has been obtained in two tests in the climate houses and in one field test.

In Climate House Studies No. 6, plants of variety 37–1933 were grown in shade vs no shade at three air temperatures and two root temperatures. The percentages of total P in internodes 8–10 of plants eight months old are presented in Table 24, which shows that the shade plants averaged 0.447 while the no shade plants averaged 0.387 per cent total P.

In Climate House Studies No. 8, plants of variety 37-1933 were grown in shade vs no shade at Makiki air temperature (average 79.2° F.) compared with constant air temperature (77° F. day and night). The 8–10 P results of plants harvested at seven months are recorded in Table 25.

TABLE 24. EFFECT OF CLIMATE ON 8–10 P—CLIMATE HOUSE STUDIES NO. 6
Var. 37–1933 Age: 8 months

Air Temperature	Root Temperature	Shade	8–10 P
Makiki (73.6°F)	62°	Shade	.351
"	"	No Shade	.321
"	72°	Shade	.307
"	"	No Shade	.270
Cool House (63°F)	62°	Shade	.439
" "	"	No Shade	.457
" "	72°	Shade	.418
" "	"	No Shade	.416
Cold House (56.5°F)	62°	Shade	.537
" "	"	No Shade	.317
" "	72°	Shade	.632
" "	"	No Shade	.544
		Av. Shade	.447
		Av. No Shade	.387
		Av. Makiki Air Temperature	.312
		Av. Cool House Air Temperature	.432
		Av. Cold House Air Temperature	.507
		Av. 72° Root Temperature	.431
		Av. 62° Root Temperature	.404

TABLE 25. CLIMATE HOUSE STUDIES NO. 8 VAR. 37–1933 AGE: 7 MONTHS

Air Temperature	Shade	8–10 P
Makiki (Av. 79.2°F)	Shade	.342
"	No Shade	.251
Constant (77°F)	Shade	.295
"	No Shade	.245

Two harvests from a shade study in the field at Makiki have been sampled, both of which resulted in higher 8–10 P in the shade than in no shade, as shown in Table 26.

Temperature

Table 23 shows increasing percentages of 8–10 P with decreasing air temperature. But in the Climate House Studies No. 2 (Hot, Makiki, and Cold air témperatures) there was no effect of air temperature on 8–10 P.

Root temperatures in the Climate House Studies No. 2 with their 8–10 P values were as follows: 90° F, 0.131% P; 80° F, 0.154% P; 70° F, 0.151% P; 60° F, 0.160% P. This suggested trend of an increase in 8–10 P with a decrease in root temperature was not obtained in Climate House Studies No. 6, as shown in Table 23.

All the values for 8–10 P in the Climate House Studies are very high, because the phosphorus supply was high. To study the effect of climate on phosphorus content of the plant, a Climate House Study is needed in which the phosphorus supply is 2 ppm P.

To recapitulate, the following factors have been found to increase the percentage of total P in internodes 8–10: 1. Increased supply of phosphorus; 2. De-

TABLE 26. SHADE STUDY IN THE FIELD AT MAKIKI. VAR. 44–3098
TOTAL P IN INTERNODES 8–10 AS % DRY WEIGHT

Age	Shade	No Shade
7 months	.234	.187
1 year	.180	.159

creased supply of K, N, Ca or Mg; 3. Shade; 4. Age. These and other factors must be considered in weighing the results presented in Section I. Another important factor not yet studied by the writer is soil moisture. Gilbert (5) remarked that phosphorus deficiency in crops is more severe in times of drought than in times of adequate rainfall. In borderline situations, he suggested that crops may be deficient only in dry seasons or dry years, due to the fact that soil phosphorus becomes available slowly in dry seasons.

DISCUSSIONS

The object of this study is to determine the critical ranges for phosphorus in internodes 8–10. Criteria to be discussed are: significance of differences in TSA in previous and current crops; 8–10 P and TSA in comparable ecological conditions; 8–10 P compared with soil P levels; response and economic levels.

Selection of Critical Ranges Based on Significance of Differences in TSA in Previous and Current Crops

The use of experiments showing significant or no significant differences in results as a basis for selecting critical levels will lead to a range of values, being a function of the sensitivity of the individual experiments. In general, our field experiments are sensitive to differences of from 0.7 to 1.0 TSA. They could be made sensitive to differences of from 0.3 to 0.6 TSA, or any other desired range, simply by increased replication.

The results presented in Section I are summarized in Table 27 in which the experiments are listed in the order of increasing level of phosphorus in the average of all plots which had received no phosphate. Table 27 is taken from a Special Release (7) in which the yield response is that obtained from the previous crop of the experiment for tons sugar per acre. This yield response in the previous crop was significant (yes) in all the experiments when the phosphorus level in internodes 8–10 of the zero phosphate plots was 0.031 or less. But when the phosphorus level was 0.032 or more, the yield response was not significant (ns).

Although there was no overlap between the "yes" and the "ns" yield responses in the previous crop, as shown in Table 27, overlap was expected and obtained when the current harvest data were summarized, as shown in Table 28, which includes all the experiments for which current yield data were available, i.e., yield data from the same crop which had been tested for phosphorus in internodes 8–10.

TABLE 27. TOTAL PHOSPHORUS IN INTERNODES 8–10 COMPARED WITH YIELD RESPONSE IN PREVIOUS CROP.

Phosphorus level total P in 8–10 internodes of O P_2O_5 plots % dry wt.	Plantation and Experiment	Yield response in previous crop	Cane variety	Date and age when sampled	Elevation	Effect of additional P_2O_5 on phosphorus level: P_2O_5 lbs./acre	Sig.	% gain	Remarks
.020	Olaa 105 A × FP	Yes	44–3098	Mar. 3, '55 1st rat. 8 mos., 3 wks.	600′	200	**	35.0	
.021	Lihue 354 AP × K	ns(P1.) Yes (1st rat.)	37–1933	Mar. 9,'55 2nd rat. 7 mos., 1 wk.	185′	100 200	** **	19.0 47.6	
.021	Hilo 163(a) A × FP	No data	44–3098	Mar. 3, '55 plant 11 mos.. 3 wks.	850′	419	ns	23.8	C.V. high, 3 replicates only
.022	Pepeekeo 82 A × FP	Yes	44–3098	Nov. 4, '53 1st rat. 7 mos., 2 wks.	700′	400	**	54.5	

TABLE 27. TOTAL PHOSPHORUS IN INTERNODES 8–10 (Concluded)
COMPARED WITH YIELD RESPONSE IN PREVIOUS CROP.

Phosphorus level total P in 8–10 internodes of O P_2O_5 plots % dry wt.	Plantation and Experiment	Yield response in previous crop	Cane variety	Date and age when sampled	Ele-va-tion	Effect of additional P_2O_5 on phosphorus level			Remarks
						P_2O_5 lbs./acre	Sig.	% gain	
.022	Olaa 103 AFP(res.)	Yes	44–3098	June 14, '54 1st rat. 8 mos., 2 wks.	300′	400(res.) 400(res.) +200(cur.)	** **	31.8 81.8	
.026	Olaa 101(a & b) APCa × ANK	Yes	44–3098	July 13, '54 1st rat. (a) 11 mos., 1 wk. (b) 11 mos., 3 wks.	1600′	200	**	46.1	
.027	Pepeekeo 82 A × FP	Yes	44–3098	Dec. 22, '53 1st rat. 9 mos.	700′	400	**	74.1	
.027	Laupahoehoe 36 A × FP	Yes	38–2915	Mar. 7, '55 1st rat. 9 mos., 2 wks.	1200′	200(res.) +200(cur.) 400(res.) + 0(cur.)	** **	77.8 51.8	
.029	Olaa 101(a) AP Ca × ANK	Yes	44–3098	Feb. 3, '54 1st rat. 6 mos.	1600′	200	**	82.7	
.030	Olaa 109(a) res. AP × CaO	Yes	44–3098	Jan. 12, '55 8 mos., 3 wks.	1500′	200(res.) +200(cur.) 400(res.) + 0(cur.)	** **	46.7 26.7	
.031	Olaa 101(a & b) AP Ca × ANK	Yes	44–3098	June 14, '54 1st rat. (a) 10 mos., 1 wk. (b) 10 mos., 3 wks.	1600′	200	**	48.4	
.031	Paauhau 107(b) AP × K	Yes	38–2915	Jan. 6, '55 1st rat. 6 mos.	1350′	200(res.) 400(res.)	ns ns	6.4 0.0	Only res. P_2O_5
.032	Pepeekeo 88 A × FP	ns	44–3098	Mar. 21, '55 11 mos. 1st rat.	400′	200(res.) +200(cur.) 400(res.) + 0(cur.)	ns ns	46.9 6.2	C.V. high
.035	Lihue 339 AP × K	ns(pl.) ns(1st rat.)	38–2915	Mar. 7, '55 2nd rat. 10 mos., 2 wks.	375′	250 1000	**	42.8 100.0	
.037	Kohala 198(b)	no data no visible difference	38–2915	June 16, '54 plant 12 mos.	475′ to 500′	500	ns	40.5	C.V. high
.039	Onomea 71 A × FP	ns	44–3098	Mar. 7, '55 1st rat. 6 mos.	1400′	200(res.) +200(cur.) 400(res.) + 0(cur.)	** **	84.6 94.9	
.040	Grove Farm 141 AP	ns	44–3098	Apr. 27, '55 1st rat. 6 mos.	370′	200(res.) +200(cur.)	**	122.0	
.045	Hakalau 119(a) A× FP (res.)	ns	44–3098	June 15, '54 1st rat. 12 mos., 2 wks.	1050′	200(res.) +200(cur.) 400(res.) + 0(cur.)	*	60.0	
.049	Paauhau 107(a) Res. AP × AK	ns	38–2915	Aug. 25, '54 1st rat. 12 mos., 2 wks.	1525′	200(res.) 400(res.)	ns ns	−10.2 8.2	Only res. P_2O_5
.050	Hakalau 118 AP × Ca	ns	44–3098	June 15, '54 1st rat. 11 mos., 3 wks.	1350′	200	**	40.0	
.059	Hakalau 124 A × FP	ns	44–3098	Mar. 7, '55 1st rat. 6 mos., 3 wks.	1200′	200(res.) +200(cur.) 400(res.) + 0(cur.)	** **	91.5 47.4	
.064	Lihue 351 AP × K	ns	44–3098	Dec. 1, '54 1st rat. 9 mos.	325′	200 400	** **	40.6 45.3	
.065	Kohala 198(c) A × FP	no data no visible difference	38–2915	June 16, '54 plant 11 mos., 2 wks.	750′ to 825′	500	ns	16.9	
.110	Kohala 198(a) A × FP	no data no visible difference	44–3098	June 16, '54 plant 12 mos., 1 wk.	275′ to 450′	500	ns	4.5	
.117	Kohala 199 AP	no data no visible difference	38–2915	June 17, '54 plant 9 mos., 3 wks.	425′ to 550′	150 300	ns ns	−1.7 −14.5	
.125	Kohala 198(d) A × FP	no data no visible difference	38–2915	June 16, '54 plant 11 mos., 1 wk.	750′ to 825′	500	ns	−17.6	

Table 28 shows that when the phosphorus percentage was 0.040 or more, there was no experiment in which a significant yield gain was obtained from phosphate. Therefore, yield gains are not to be expected in this range. When the phosphorus percentage was 0.032 to 0.039, there was only one experiment in which a significant yield gain was obtained from phosphate (Onomea 71). Therefore, yield gains may occasionally be expected in this borderline range.

When the phosphorus percentage was 0.031 or less, more than half of the responses were significant. All but one of the experiments which had no significant response in yield had been sampled for phosphorus in November, December and January—the season of slow growth. Therefore, yield gains are generally to be expected in this range, if the samples for phosphorus are taken in a season of good growth and if the phosphorus applied is absorbed by the plants.

TABLE 28. TOTAL PHOSPHORUS IN INTERNODES 8–10 COMPARED WITH YIELD RESPONSE IN CURRENT CROP.

Phosphorus level Total P in 8–10 internodes of O P_2O_5 plots as % dry weight	Plantation and Experiment	Soil P ppm P	lbs./ Ac.Ft.	Month Sampled for P	Yield response in current Crop	Remarks
.021	Lihue 354 AP × K	13	38	March	yes	for 500# K_20
.021	Hilo 163(a) A × FP			March	ns	nearly 12 mos. old when sampled for P
.022	Pepeekeo 82 A × FP	14	21	November	ns	slow growing season
.022	Olaa 103 AFP (res.)	25	11	June	yes	
.026	Olaa 101(a&b) APCa × ANK	28	26	July	yes	
.027	Laupahoehoe 36 A × FP	12	22	March	yes	
.027	Pepeekeo 82 A × FP	14	21	December	ns	slow growing season
.029	Olaa 101(a) APCa × ANK	28	26	February	yes	
.030	Olaa 109(a) res. AP × CaO	16 20 41	15 23 48	January	ns	sampled May–June was .034
.031	Olaa 101(a&b) APCa × ANK	28	26	June	yes	
.031	Paauhau 107(b) AP × K	42	76	January	ns	Current crop received no P_2O_5; ns for total P
.035	Lihue 339 AP × K	12	35	March	ns	
.039	Onomea 71 A × FP	10	15	March	ns—200 lbs. yes—400 lbs.	
.040	Grove Farm 141 AP	10	29	April	ns	
.049	Paauhau 107(a) Res. AP × AK	44	79	August	ns	
.050	Hakalau 118 AP × Ca	22	33	June	ns	
.064	Lihue 351 AP × K	15	44	December	ns	

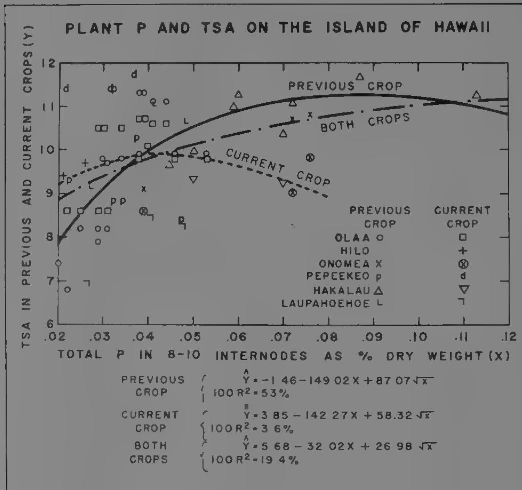

Figure 6. Plant P and TSA in comparable ecological conditions along the Hilo Coast of the island of Hawaii.

8–10 P and TSA in Comparable Ecological Conditions.

A fault of the criterion of significance of gains in TSA lies in the fact that most gains from phosphate are small, for which reason many replicates are required to prove their significance. Several tests in this study gave rather large gains in yield which were not statistically significant. An attempt was made to make use of all data available, without regard to statistical significance of the individual experiment. Experiments chosen for this study were taken from comparable ecological conditions along the Hilo coast and included the following plantations: Olaa, Hilo, Onomea, Pepeekeo, Hakalau and Laupahoehoe.

All available data for TSA and 8–10 P from all tests on these plantations were used for calculation of regression coefficients. The resulting curves are plotted in Figure 6. Previous and current crops are plotted separately and also both crops together. All the previous crops were plant cane, and all the current crops (except Hilo) were ratoons.

There is a very wide scatter and the regression coefficients are low. However, the curves for previous and current crops each rise at the left, the rise being greater and longer in the curve for the previous crop than in the curve for the current crop.

In the plot for the previous (plant) crop, TSA continues to rise even at 0.07 per cent total P in internodes 8–10. Probably not all of this rise is actually due to phosphorus, for it is well known that soils rich in phosphorus are also rich in other good characteristics. Yield as a function of 8-10 P accounted for 53 per cent of the yield variation in the previous crop. This is particularly important because the remaining variation includes that due to locations.

The plot for the current crop (first ratoon except Hilo, which was plant cane) shows a rise in TSA reaching a maximum at 0.04 per cent total P in internodes

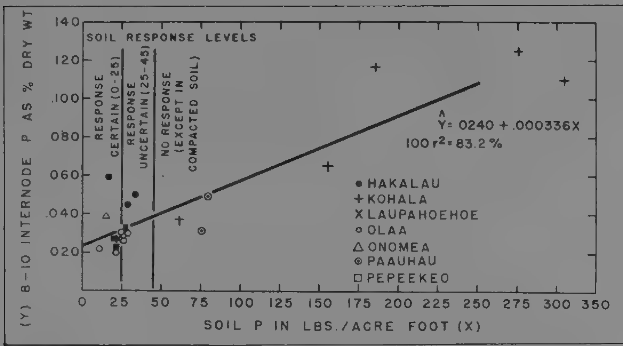

Figure 7. Soil P and plant P on the island of Hawaii. 8-10 internode P is that of the check plots.

8–10, followed by a steady decrease to 0.080, there being no current crop data available beyond that point.

When both crops are plotted in a single curve, there is a gradual continuous rise throughout the curve.

Analyzing the data by this method indicates the possibility of a gain in TSA in the current crop with phosphorus up to but not beyond 0.04 per cent total phosphorus in internodes 8–10.

A comparison of responses by plant cane and ratoons has also been made by Clements (4).

8–10 P Compared with Soil P Levels.

The values for soil phosphorus are expressed both in parts per million and pounds per acre foot. From a study of more than 100 field experiments, Ayres and Humbert (1) determined the following critical ranges for soil phosphorus levels:

Soil P range lbs./Ac. Ft.	Response
Below 25	Certain
25–45	Uncertain
Above 45	None (except in compacted soil)

To find the 8–10 P expected at these soil P levels, a graph of the check plots was prepared with soil P in pounds per acre foot on the X axis and 8–10 internode P on the Y axis (Figure 7). For this study, all the experiments on the island of Hawaii (except Hilo) were used. Hilo was omitted because of uncertainty as to the soil P value. The coefficient was high (83.2 per cent) meaning that 83 per cent of the variation in plant phosphorus was explained by variation in soil phosphorus.

Vertical lines were drawn to separate the soil response levels. The line at 25 pounds per acre foot, separating "response certain" from "response uncertain" crossed the 8–10 internode P line at 0.032. The line at 45 pounds per acre foot, separating "response uncertain" from "no response" crossed the 8–10 internode P line at 0.038.

Response and Economic Levels

In Figure 8 is presented a response curve prepared from the same experiments used in Figure 6. Cost in TSA of the application of 200 pounds P_2O_5 is shown in

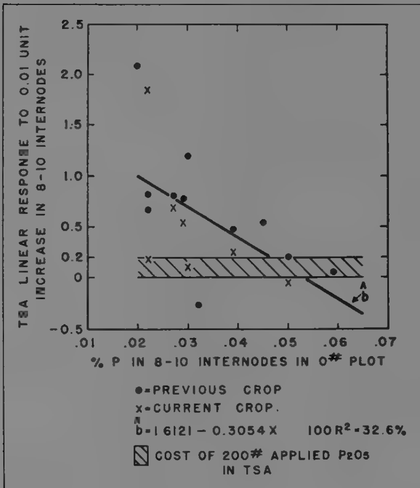

Figure 8. Economy response to P as related to 8-10 internode values in check plots.

the hatched area. The response line crosses the cost line at 0.046 per cent P in internodes 8–10. Little, if any, economic response could be expected at 8–10 P levels greater than 0.040 per cent.

Critical ranges for 8–10 P as determined by a consideration of the above four criteria are brought together for comparison in Table 29. The table on the whole shows considerable uniformity.

Local conditions would, of course, affect the application of these levels to a particular field. All these levels are estimated levels based upon a statistical analysis of the data. Both stalks and plots vary.

Several factors have been found to affect the absorption of phosphorus and phosphorus content of the plant. The effects of supply of P, K, N, Ca and Mg, variety, primary or sucker stalks, shade or no shade, and temperature are dealt with in Section II of Results. The American Factors Test (2) showed that high nitrogen depresses the phosphorus level in internodes 8–10; the need for phosphorus depends on the level of nitrogen as well as time of sampling; total phosphorus in internodes 8–10 varies with season and age of plant, being lowest at 8–12 months of age. The effect of season was also mentioned by Clements (3), who stated that samples for phosphorus should be taken in the summer. He also

TABLE 29. CRITICAL RANGES FOR 8-10 P

Criterion	Yield gains expected P needed	Occasionally expected P perhaps needed	Not expected P not needed
Significance of differences in TSA	Below 0.032	0.032–0.039	0.040 and more
TSA in comparable ecological conditions (current crop)	up to 0.040		more than 0.040
8–10P compared with Soil P levels	Below 0.032	0.032–0.038	more than 0.038
Economic response	Below 0.040	0.040–0.045	0.046 and more

stated that in a severe potash deficiency, phosphate depressed yield. Hartt (6) reported that plants deficient in potassium accumulated large amounts of phosphorus.

For these reasons, a single set of samples may be insufficient to indicate the true need for phosphate. Two to four sets of samples taken at intervals during the growing season, along with soil analysis, should give a clear indication of the need to apply phosphorus in the field.

CONCLUSION

Total phosphorus in internodes 8–10 determined in samples collected during a good growing season, from plants aged approximately six to 12 months, may aid in determining the need for applications of phosphate in the field.

With phosphorus percentages below 0.032, yield gains from phosphate applications may be expected if the added phosphate is absorbed by the plant and if no other factor interferes. There is, in addition, some evidence of economic response with phosphorus percentages up to 0.040.

With phosphorus percentages ranging from 0.032 to 0.040 (or 0.045 depending upon the criterion used), phosphorus may be applied as insurance because yield gains are expected occasionally in this borderline range.

With phosphorus levels more than 0.038 to 0.046 (depending on the criterion used), yield gains are not expected and phosphorus applications are not needed.

83 per cent of the variation in plant phosphorus is due to variation in soil phosphorus.

The amount of phosphorus in internodes 8–10 is affected by other fertilizer elements, e.g., K, N, Ca, Mg, as well as age of plant, season of sampling, amount of light, and other climatic and edaphic factors.

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LITERATURE CITED

1.* Ayrès, A. S. and R. P. Humbert, 1957. Single critical levels for soil phosphorus and potassium. H.S.P.A. Special Release No. 155, pp. 1–4.

2. Burr, G. O., 1955. Plant analyses as indexes of nutrient availability and adequacy. Hawaiian Planters' Record, Vol. 55, pp. 103–109.

3. Clements, H. F., 1955. The absorption and distribution of phosphorus in the sugar cane plant. Hawaiian Planters' Record, Vol. 55, pp. 17–32.

4. Clements, H. F., 1958. Recent developments in the crop-logging of sugar cane—phosphorus and calcium. Haw. Agr. Exp. Sta., Col. of Agri., Univ. of Haw., Progress Notes No. 114, pp. 1–16.

5. Gilbert, F. A., 1957. Mineral nutrition and the balance of life. Norman: Univ. of Oklahoma Press, pp. 1–350.

6. Hartt, C. E., 1955. The phosphorus nutrition of sugar cane. Hawaiian Planters' Record, Vol. 55, pp. 33–45.

7.* Hartt, C. E. and A. S. Ayres, 1955. Stalk phosphorus as a guide to the phosphate fertilization of sugar cane and its relation to soil phosphorus. HSPA Special Release No. 121, pp. 1–8.

8. Humbert, R. P., 1958. Personal communication.

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